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SIMULATION OF THE TIME-DEPENDENT PERFORMANCE OF THE ACTIVATED SLUDGE PROCESS USING THE DIGITAL COMPUTER

Robert Smith, et al

Advanced Waste Treatment Branch
Cincinnati, Ohio

October 1970

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By
Robert Smith
Richard G. Eilers

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Details of illustrations in
this document may be better
studied on microfiche.

INTRODUCTION

One ~~of the most~~ challenging and ~~still~~ unsolved problem~~s~~ associated with wastewater treatment technology is the development of a mathematical model capable of simulating the time-dependent performance of the activated sludge process, ~~A major obstacle in~~ especially ~~finding such a model is~~ a representation of the time-dependent characteristics of the final settler. Adequate relationships for the final settler are not available even for 24-hour composite performance variables. Models for the biological aspects of the process have been proposed and some have been tested in bench-scale experiments[1,2,3] with dissolved substrates. At the present time no model, even for the biological aspects, has been developed which has sufficient authority to be used as a basis for design of automatic control schemes in full-sized plants.

The goal of ~~any~~ automatic control ~~scheme~~ is to produce an effluent which is of better average quality than that which can be achieved without control and to minimize the variation of effluent quality with time. Minimizing the variation in effluent quality can be important when advanced processes which are sensitive to overloads of particulate or dissolved species are used downstream of the activated sludge process. Improving the average discharge of water contaminants is important for protection of the receiving stream.

Successful application of many of the control schemes which have been suggested is not necessarily dependent on the development of a valid model of the process. The model can be useful, however, in computing the advantages to be gained from installation of various kinds of control schemes and in interpreting measurements made on full-sized plants utilizing a particular control scheme.

Some control schemes which have been proposed to either improve the performance of the process or to achieve the same performance at reduced cost are listed below:

1. Sense the level of the sludge blanket in the final settler and adjust the flow rate in the return stream to keep the sludge blanket level at a predetermined set point.

2. Sense the dissolved oxygen concentration in the aerator and adjust the flow of air to the aerator to hold the dissolved oxygen level at some set point.

3. The volume flow of air supplied in response to the demand of the dissolved oxygen meter can be used as a measure of the biological activity. Stored activated sludge can be returned to the aerator at a rate which is some function of the air supply rate.

4. Control the volume flow or mass flow of the waste activated sludge stream to hold the mixed liquor volatile suspended solids in the aerator at some set point or at a level related to the load on the process.

5. Return stored activated sludge to the aerator in response to either the organic load on the process or the effluent quality.

6. Use equalization or holding basins upstream of the process to smooth the hydraulic and organic loadings on the process.

A key limitation on implementation of most of the control schemes listed above is the lack of adequate online instrumentation for measuring such parameters as concentration of dissolved and particulate organics in the influent and effluent streams, biodegradability of organics present, concentration of mixed liquor volatile suspended solids and sludge blanket level on a continuous basis.

TIME VARYING LOADS ON THE PROCESS

The stream of sewage entering most sewage treatment plants varies significantly throughout the day in both volume flow and contaminant concentration. This is caused by the habits of the population served and the hydraulic characteristics of the sewerage system. The extent of this variation is shown in References 4-7 which report measurements made on operating plants. As a result of this variation in the plant influent stream, the quality of the effluent stream from processes such as the primary settler or the activated sludge process also varies.

Measurement of peak flows versus 24-hour average flows in trunk sewers from residential communities in Orange County, California was reported in a study by Boyle Engineering and Lowry and Associates[8]. The data fitted the following relationship:

$$\text{Peak Flow, mgd} = 1.84\ (\text{Average Flow, mgd})^{0.92}$$

The peak to average ratio thus decreases as the average flow increases. The time-dependent behavior of the activated sludge process is also of interest in industrial applications when the wastewater is produced during a portion of the day or week and must be stored and fed to the process at a more constant rate to avoid collapse of the process.

DESCRIPTION OF THE MODEL

This report describes a digital computer program for simulating the time-dependent behavior of the biological aspects of the activated sludge process. The system simulated is shown in Figure 1. Generally accepted relationships for biological activity are used but no assurance can be given that the program accurately represents the time-dependent behavior of the process. A limited amount of time-dependent data has been gathered at the Hyperion plant in Los Angeles and this data has been used to test the validity of the model. As pointed out previously, representing the performance of the final settler is one of the most severe limitations of the model.

The digital computer program which simulates the performance of the activated sludge process consists of a numerical integration of the mass balance and biological rate equations which are assumed to represent the process. The first numerical integration scheme tried was the method of "Forward and Successive Integrations" described by Milne[9]. This method yielded solutions which oscillated with increasing amplitude. This method was, therefore, abandoned and the fourth order Runge-Kutta method[10] was installed. The Runge-Kutta method performed satisfactorily and agreed well with a similar program developed by Dr. Carl Evert[11] using the Control Data Corp. COBLOC language for simulating the analog computer with the digital computer. The Runge-Kutta method complicated the logic of the program and was relatively expensive in terms of computing time. Comparisons were then made between the Runge-Kutta method and simply multiplying

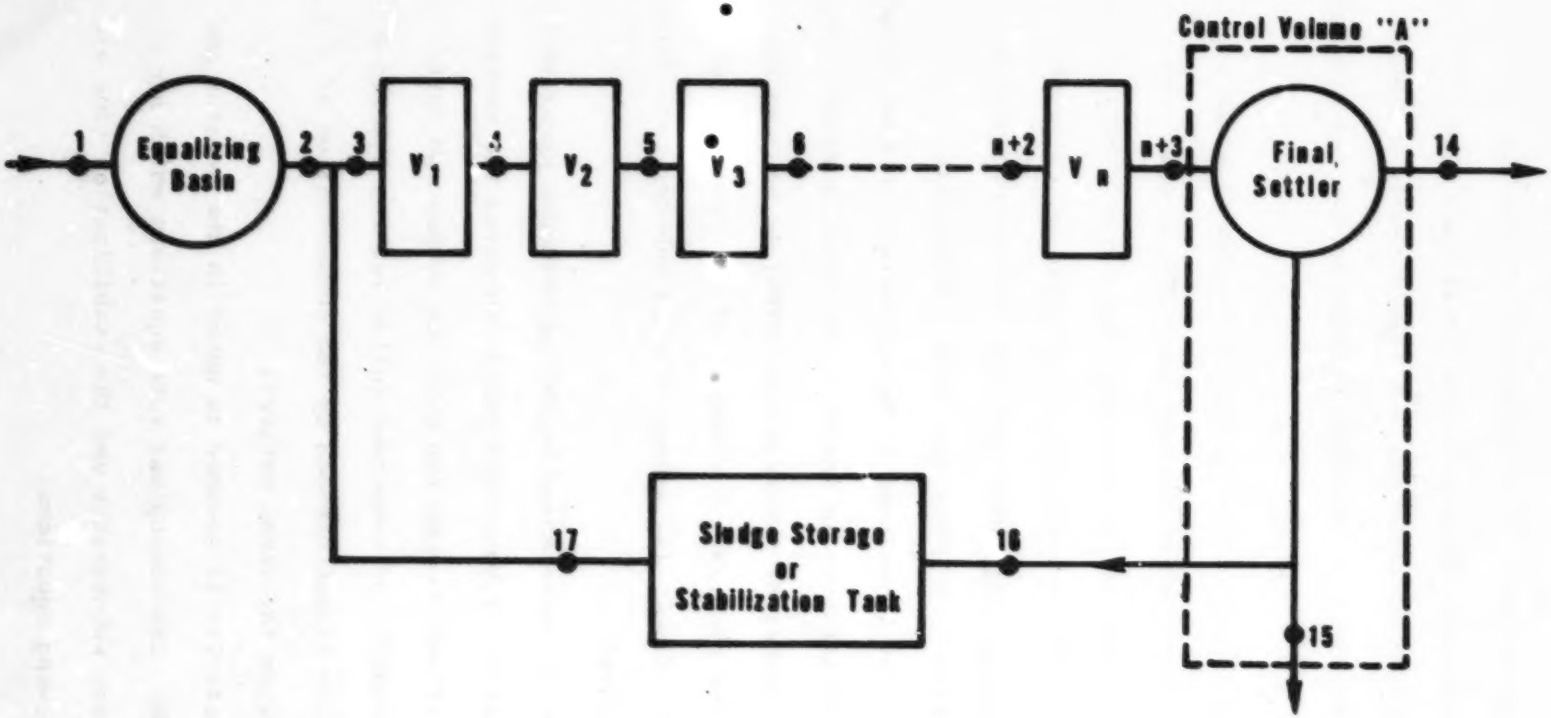

Control Volume "A"
1
Equalizing Basin
2
3
V_1
4
V_2
5
V_3
6
n+2
V_n
n+3
Final Settler
14
15
16
Sludge Storage or Stabilization Tank
17

FIGURE 1

SCHEMATIC DIAGRAM
FOR
TIME-DEPENDENT SIMULATION OF ACTIVATED SLUDGE PROCESS

the computed derivative by the time increment to obtain the increment in the dependent variable. It was found that this simplified procedure produced solutions not significantly different from the Runge-Kutta method. It was then decided to use the simplified method exclusively.

As the program now stands three classes of microorganisms are considered; first, heterotrophs which use 5-day BOD as substrate and produce new cells, carbon dioxide, and water, second, Nitrosomonas which uses ammonia nitrogen as substrate to produce new cells and nitrite, and third, Nitrobacter which uses the nitrite produced by Nitrosomonas as substrate to produce new cells and nitrate.

Mixing in the aerator is assumed to be equivalent to some number of completely mixed sub-aerators in series. The total aerator volume (VAER) and the number of sub-aerators (NTKS) to be used are supplied as input to the program. Any number of sub-aerators between one and ten may be specified. The volume of each sub-aerator, V(I), is then taken as VAER/NTKS.

The final settler is represented by two performance parameters; XRSS which is the fraction of suspended solids entering the settler which escape in the effluent stream, and URSS the compaction ratio defined as the concentration of suspended solids leaving the final settler in the underflow stream divided by the concentration of suspended solids entering the final settler.

All biological activity is assumed to occur in the aerator and the stabilization tank. The biological rate equations which are assumed to apply to each sub-aerator and the stabilization tank are expressed by the following equations:

$$\frac{dS_i}{dt} = \frac{Q_i(S_{i-1} - S_i)}{V_i} - \frac{C_1 S_i X_i}{C_4(C_2 + S_i)} \qquad (1)$$

$$\frac{dX_i}{dt} = \frac{Q_i(X_{i-1} - X_i)}{V_i} + \frac{C_1 S_i X_i}{C_2 + S_i} - C_3 X_i \qquad (2)$$

S = substrate concentration, mg/l
X = concentration of microorganisms, mg/l
Q = flow, mgd
V = volume of sub-aerator, mg
t = time, days
i = station number downstream of sub-aerator
C_1, C_2, C_3, C_4 = constants

The first term in each equation represents the physical displacement of microorganisms and substrate due to the influent and effluent streams. The second terms represent the growth of microorganisms and the corresponding use of substrate based on the Monod[12] expression. The third term of equation (2) represents the loss of cells through lysis. C_3 is set equal to zero for Nitrosomonas and Nitrobacter after the work of Downing[13]. Nominal values for the rate and yield constants for the three classes of bacteria considered are shown in Table I.

Equations (1) and (2) are strictly correct for both heterotrophs and Nitrosomonas. For Nitrobacter, however, the rate of change of substrate (NO_2^-) equation must have an additional term to account for the production of nitrite resulting from metabolic activity of Nitrosomonas. This is not strictly correct because part of the nitrogen synthesized by Nitrosomonas is used in cell production.

— 7

7a

TABLE I

NOMINAL VALUES FOR RATE AND YIELD CONSTANTS FOR THREE CLASSES OF BACTERIA

Heterotrophs	Nitrosomonas	Nitrobacter
C_1 = 4.8 days^{-1}	C_1 = 0.28 days^{-1}	C_1 = 1.0 days^{-1}
C_2 = 150 mg/1 BOD_5	C_2 = 1.0 mg/1 NH_3-N	C_2 = 2.1 mg/1 NO_2-N
C_3 = 0.18 days^{-1}	C_3 = 0.0	C_3 = 0.0
C_4 = 0.5 lb cells/lb BOD_5	C_4 = 0.050 lb cells/lb NH_3-N	C_4 = 0.020 lb cells/lb NO_2-N

Since the amount of nitrogen used for cell production is only about 0.8% of the total amount of ammonia nitrogen used, it has been neglected in this computation.

To begin the computation, the volume of water in the equalization tank (V(2)), the volume of sludge in the stabilization tank (V(17)), and the total water volume (VAER) in all sub-aerators must be supplied as input. The flow out of each sub-aerator is assumed to equal the flow in so that the volume of water in each sub-aerator is fixed. If V(2) or V(17) are set equal to zero, logic within the program will set flow and all concentrations downstream of the tank equal to concentrations upstream of the tank.

If the finite value for V(2) or V(17) is given, a pumping schedule from the tank must be provided. The pumping schedule can be given as a function time or as a function of some performance parameter for the process. For example, the rate of pumping from the stabilization tank can be made directly proportional to the difference between a set point concentration and the concentration of substrate at station No. 14, directly proportional to the time rate of change of substrate at station No. 14, directly proportional to the integral of substrate at station No. 14, or to the sum of all three. The volume of water in the equalization tank and the stabilization tank, V(2) and V(17), can, therefore, vary with time.

Since sinusoidal relationships for both flow and BOD_5 concentration at the influent station No. 1 with a period of one day and in phase with one another are normally used; the pumping schedule from the stabilization tank would still be roughly sinusoidal in any case. Most computational studies of the effectiveness of control have, therefore, been made with a sinusoidal time schedule of pumping from the stabilization tank. A time lag (TLAG), however, is provided in the sinusoidal pumping schedule from the stabilization tank. The results of these computations will be discussed in a section of this report entitled COMPUTED RESULTS.

When a finite volume for the equalization tank is used, the schedule for pumping is normally taken as a fixed value equal to the mean of the flow function into the equalization tank. Logic provided in the program sets both V(2) and V(17) equal to zero if the computed volume is negative.

A pumping schedule for the waste activated sludge stream No. 15 must also be provided. This can be set at a constant value, made to vary sinusoidually, or be scheduled as some function of the effluent quality. The steady-state concentration of bacteria in the system is controlled by the pumping schedule selected for the waste stream. A period of about 14 days is normally required to reach the steady-state condition.

To begin the computation, it is necessary to specify the concentrations of all three substrates and all three bacteria in the effluent from each tank. Since the tanks are assumed to be completely mixed, this also corresponds to the concentration existing within the tank. If finite values are specified for V(2) and V(17), the concentrations of all substrates and all bacteria must be given for these tanks.

All three substrates are treated as dissolved material. All three classes of bacteria are treated as particulate. The performance parameters, XRSS and URSS, for the final settler are assumed to apply to each class of bacteria. In the program no consideration is given to organic or inorganic material which is inert to biological activity.

The program first computes the concentrations of all substrate and bacteria at stations 3, 14, 15 and 16 and the flow at stations 3, 14, and 16. This is done by writing mass balances around control volume "A" in Figure 1. Some of the relationships which can be derived are given below:

$$S_{14} = S_{15} = S_{16} = S_{n+3} \qquad (3)$$

$$Q_3 = Q_2 + Q_{17} \qquad (4)$$

$$Q_{14} = Q_3(\mathrm{URSS} - 1)/(\mathrm{URSS} - \mathrm{XRSS}) \qquad (5)$$

$$Q_{16} = Q_3 - Q_{14} - Q_{15} \qquad (6)$$

$$X_{14} = (\mathrm{XRSS})(X_{n+3}) \qquad (7)$$

$$X_{16} = X_{15} = \mathrm{URSS}(X_{n+3}) \qquad (8)$$

The program next computes the rates of change with respect to time for all substrates and bacteria. These rates are then multiplied by the time increment (H), which is normally taken as 0.01 days, and added to the current values to obtain the new values for all concentrations.

The new flows at stations 1, 2, 15, and 17 are then read and all flows within the system are adjusted. The rate of change for volumes V(2) and V(17) are computed and the volumes are corrected by again multiplying by H and adding the increment to the current volumes.

In a recently completed study by Smith and Eilers[14] it was found that the rate constant for synthesis (C_1) for heterotrophs is not a true constant but varies with the loading on the process. The empirical relationship developed in reference No. 14 is based on quasi-steady-state measurements and, therefore, might not be strictly applicable to the time-dependent model. The relationship, shown below, can be inserted into the time-dependent program. Computed results have been obtained with and without this correction.

$$C_1 = 5.5476 - 2.9403 \log_e (1/L) \qquad (9)$$

where,

L = process loading, lb BOD fed/day/lb heterotrophs in system.
In deriving this relationship the amount of heterotrophs in the system was taken as the total aeration volume (V(17) = 0) multiplied by the concentration of heterotrophs in the effluent stream from the aerator. For consistency, therefore, the same definition was used in the time-dependent program.

The program also integrates the product of flow and BOD$_5$ concentration in the effluent stream (No. 14) over a one day period to compute the total number of pounds of BOD discharged per day. Average values over one day are also computed for the BOD loading (lb BOD fed/day/lb heterotrophs in system) at station No. 2 and the removal of BOD for the system in terms of pounds removed per day per lb of heterotrophs in the system. Pounds of heterotrophs in the system is computed as the product of the concentration at station n+3 and the total aerator volume (VAER).

If the flow and BOD$_5$ concentrations at station No. 1 are not sinusoidal, it is possible to input any schedule by reading in the two vectors QMATX and SMATX which contain influent flow and BOD$_5$ concentration for each of 100 time points equally distributed over one day. The compaction ratio, URSS can also be supplied as a time function by use of the vector UMATX.

The program also includes logic to plot output mechanically using a plotter.

COMPUTED RESULTS

The first consideration in using the time-dependent program is to select input values for VABR and Q_{15} which will cause the system to come to equilibrium at values for dissolved BOD_5 in the effluent stream (No. 14) and concentration of heterotrophs at station No. n+3 which correspond to known operating conditions for real plants. This can be accomplished in two ways. The first is trial and error using the time-dependent program. The program normally reaches equilibrium after about 14 days of real time. The other method is to use the steady-state simulation program for the activated sludge process described in Reference 14. Both programs will compute the same results.

This kind of comparison between the two programs gave the first good indication of the degree of computational accuracy attainable with the time-dependent program. From the steady-state program it is known that about one third of the mixed liquor suspended solids held in the aerator are active heterotrophs. Since the normal concentration of mixed liquor suspended solids held is about 2000 mg/l, the steady-state program was used to compute the volume of the waste stream which would hold the active solids at 600 mg/l at the effluent stream from the aerator. One completely mixed aerator was assumed with a volume equivalent to four hours detention time based on the flow at station No. 2. V(17) was set equal to zero. The calculated volume of the waste stream (No. 15) was 0.269 mgd for a fixed 10 mgd flow at station No. 2. A second steady-state point was computed with the same influent flow and the same aerator volume but with the concentration of heterotrophs set at 1600 mg/l. The computed volume of the waste stream for this case was 0.112 mgd. The computed BOD_5 in the effluent stream was 18.75 mg/l for the first case and 7.53 mg/l for the second case using the steady-state program.

The time-dependent program was started at time zero with the steady-state values for the first case but with the volume of the waste stream set equal to the correct value for the second case. The program was then run for 28 days real time. This required 2800 time increments of 0.01 days each. The computed results are shown in Figure 2. The final computed value for heterotrophs at the effluent of the aerator was 1603 mg/l and the final BOD_5 in the effluent stream (No. 14) was 7.52 mg/l. The time-dependent program was thus shown to agree with the steady-state program within an error of about 0.2% over a 28 day period of integration. In this computation the rate constant for heterotrophs (C_1) was used as a constant (4.8 days^{-1}).

Any reasonable input values can be used with the time-dependent program and the program will approach some steady-state condition. Some results of this kind are shown in Figures 3-6.

In another computational study using the time-dependent program the flow and concentration of BOD_5 and ammonia nitrogen were varied sinusoidally at station No. 2. The sine functions used are shown below.

$$Q_2 = 10. - 3.5 \sin(6.283\ T) \tag{10}$$

$$BOD_2 = 130. - 86.6 \sin(6.283\ T) \tag{11}$$

$$NH_3\text{-}N = 30. - 20. \sin(6.283\ T) \tag{12}$$

T = time from first steady-state point in days

TRANSIENT RESPONSE OF ACTIVATED SLUDGE PROCESS
STEP CHANGE IN WASTE STREAM, Q_{15}

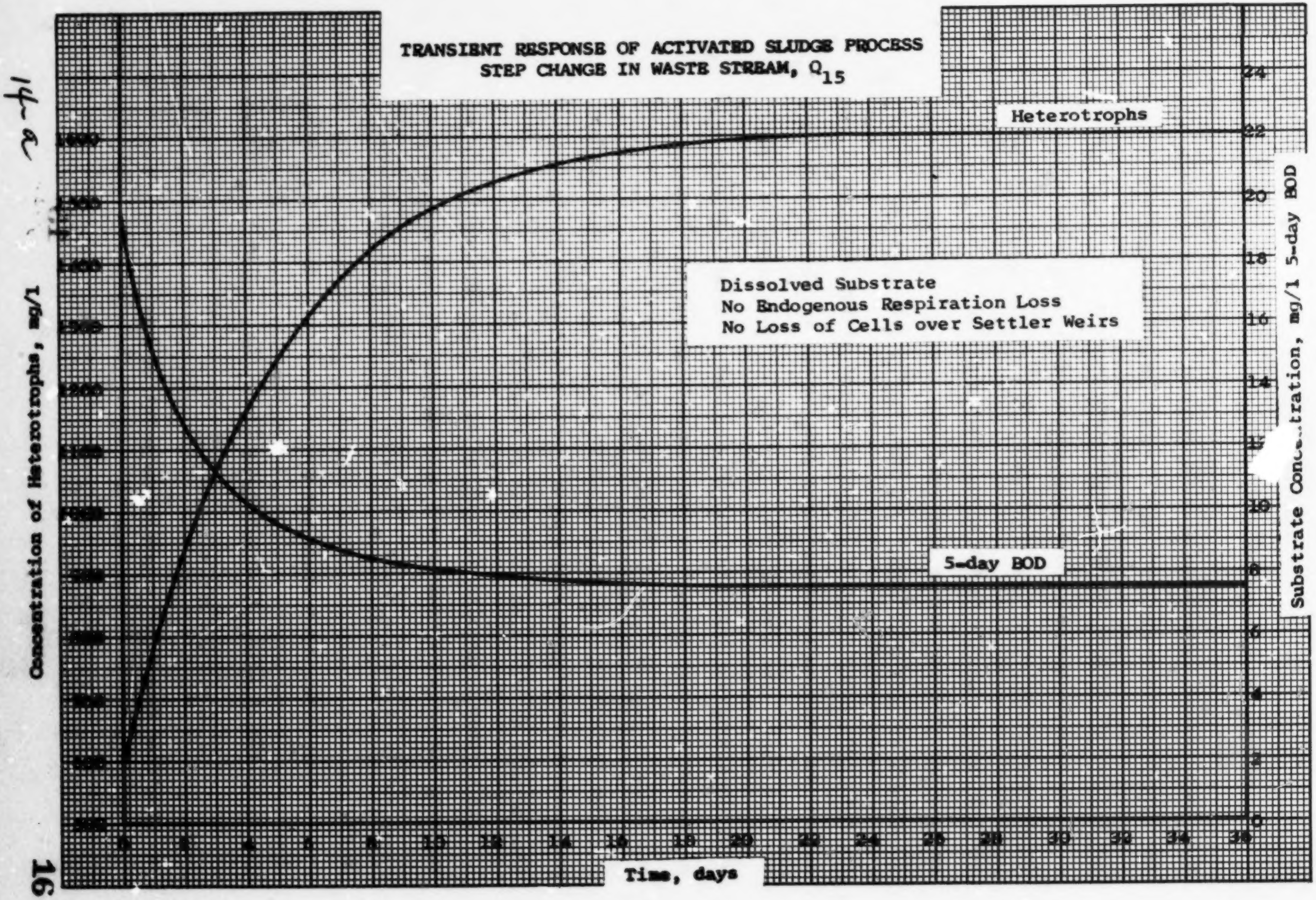
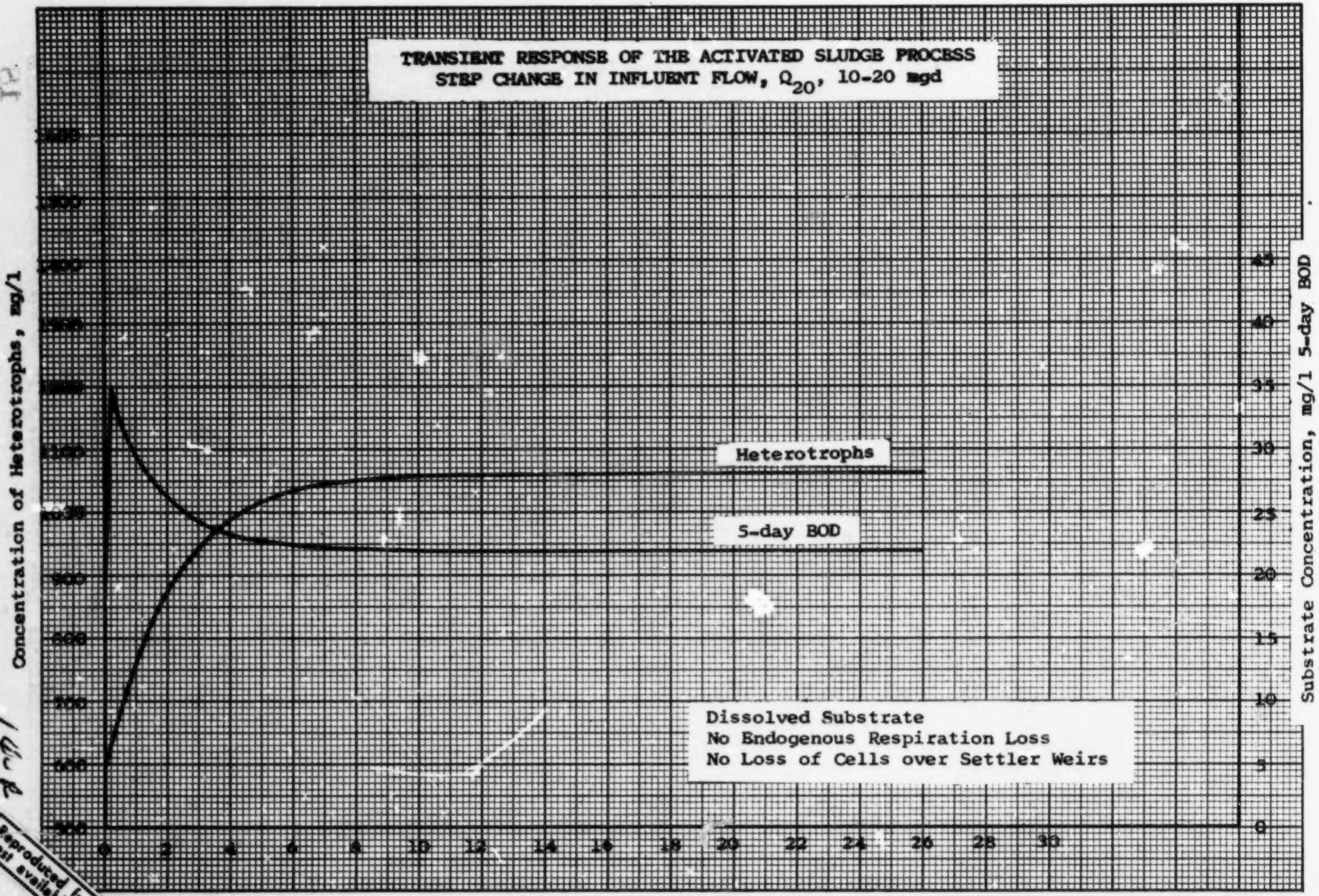


FIGURE 2



TRANSIENT RESPONSE OF THE ACTIVATED SLUDGE PROCESS
STEP CHANGE IN INFLUENT FLOW, Q_{20}, 10-20 mgd

Dissolved Substrate
No Endogenous Respiration Loss
No Loss of Cells over Settler Weirs

FIGURE 3

18

14-R

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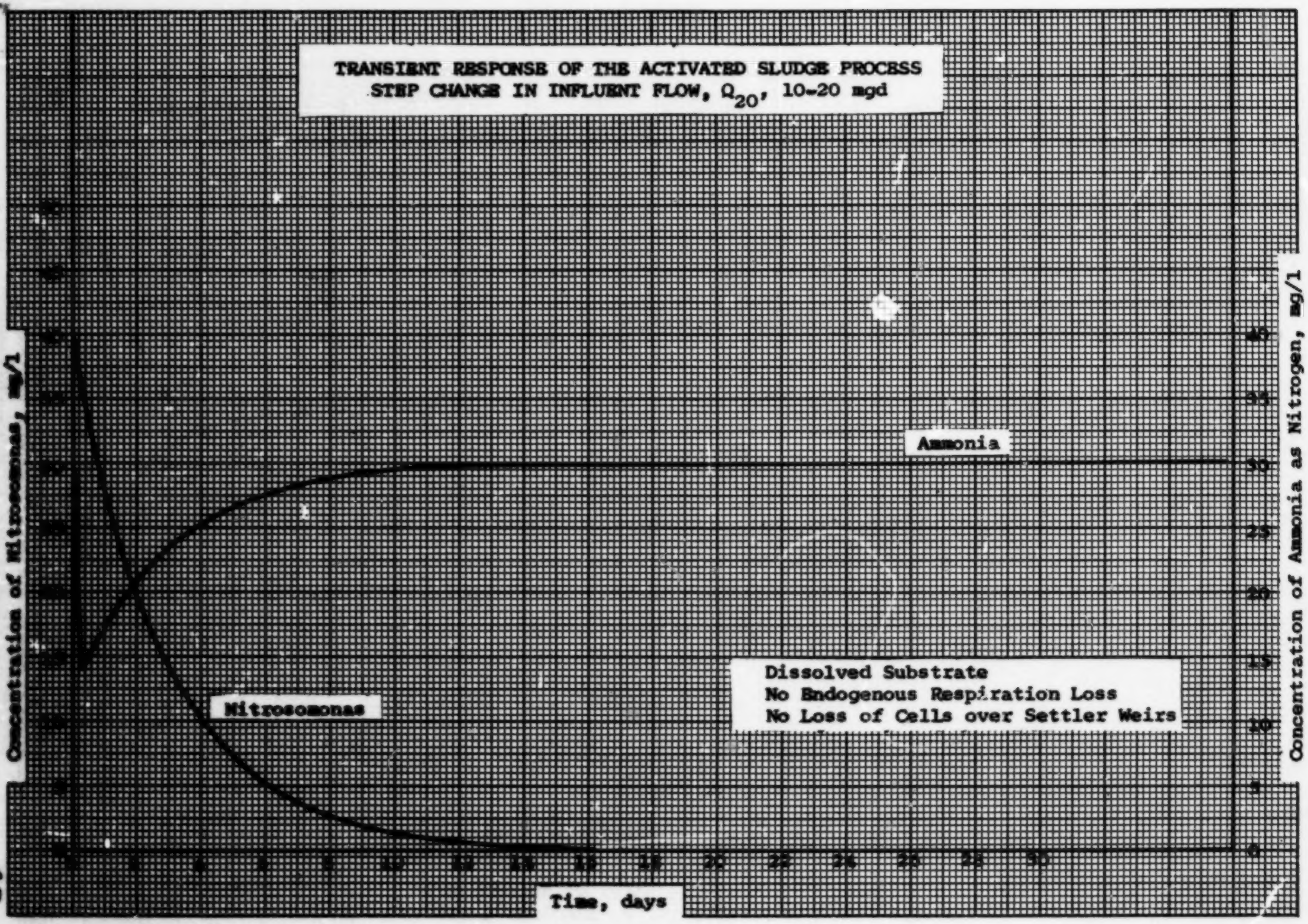
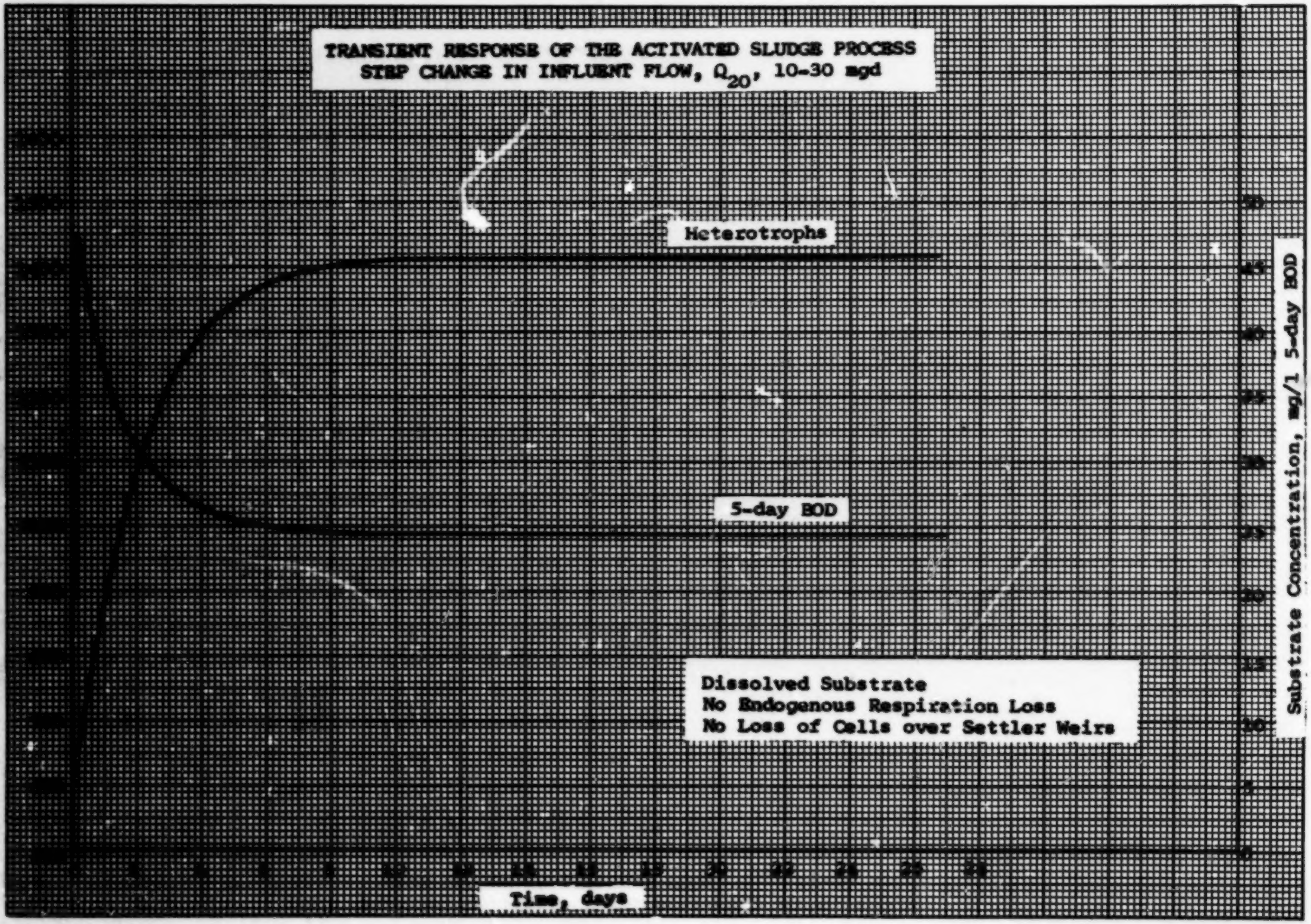

TRANSIENT RESPONSE OF THE ACTIVATED SLUDGE PROCESS
STEP CHANGE IN INFLUENT FLOW, Q_{20}, 10-20 mgd
Ammonia
Nitrosomonas
Dissolved Substrate
No Endogenous Respiration Loss
No Loss of Cells over Settler Weirs
Concentration of Nitrosomonas, mg/l
Concentration of Ammonia as Nitrogen, mg/l
0
5
10
15
20
25
30
35
40
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Time, days

FIGURE 4

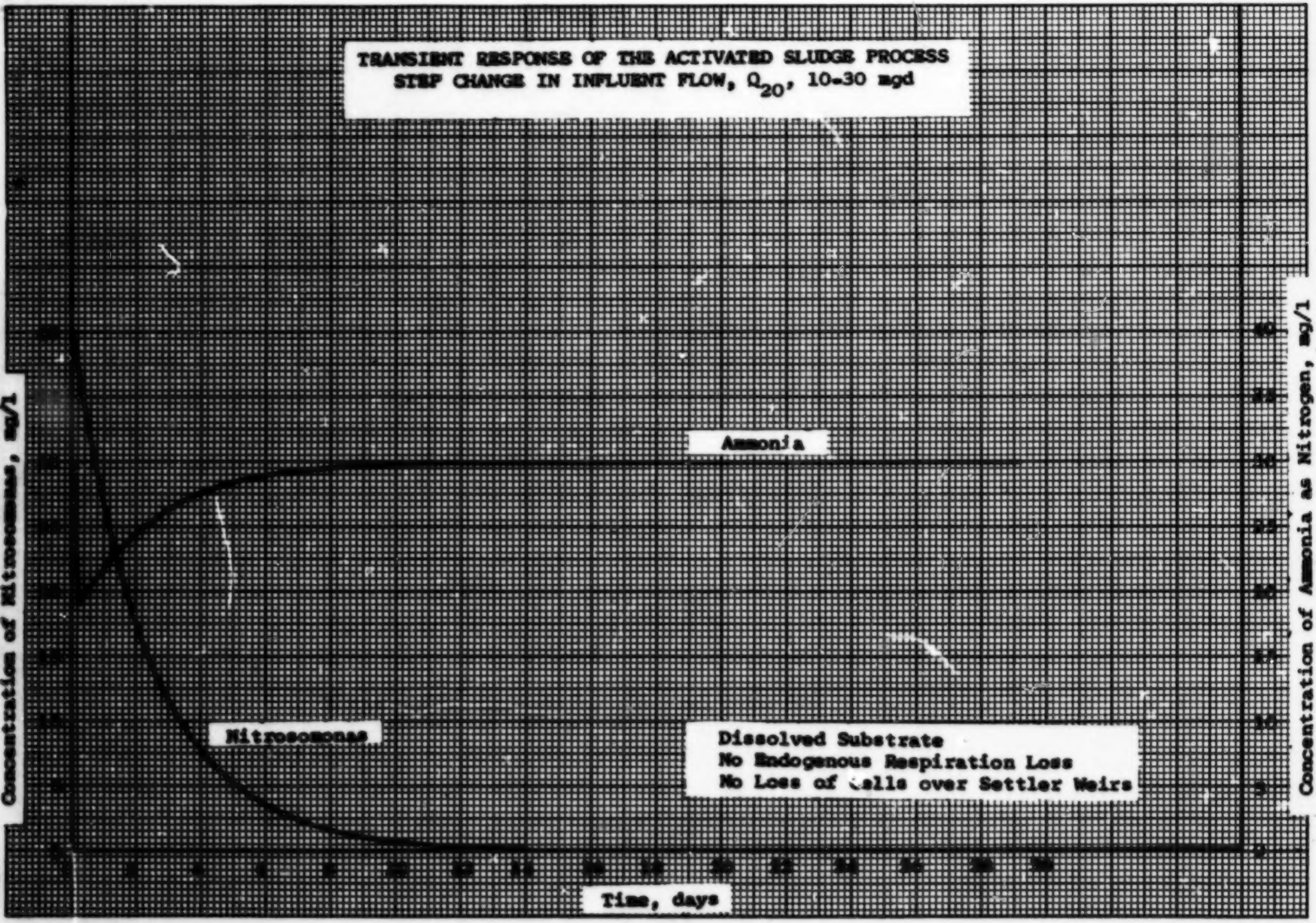
14-C



TRANSIENT RESPONSE OF THE ACTIVATED SLUDGE PROCESS
STEP CHANGE IN INFLUENT FLOW, Q_{20}, 10-30 mgd

FIGURE 5

P-41



TRANSIENT RESPONSE OF THE ACTIVATED SLUDGE PROCESS
STEP CHANGE IN INFLUENT FLOW, Q_{20}, 10-30 mgd

FIGURE 6

14-E

Some representative computed results without the surge tank are shown in Figure 7 - 10. Notice that the effluent concentration of BOD_5 is not quite sinusoidal indicating the non-linear character of the differential equations.

The equalization tank can be used in two ways; first, setting Q_2 equal to Q_1 and second, setting Q_2 at a fixed value equal to the average flow rate at station No. 1. If Q_2 is set equal to Q_1, no pumping is required but the effectiveness of the equalization tank is minimized. If Q_2 is to be held fixed at the average influent flow, the effectiveness of the tank will be maximized but a minimum size tank will be required.

The minimum size tank required when the influent flow is sinusoidal can be calculated as follows: the rate of change of the water volume in the tank is equal to the flow rate in minus the flow rate out. If we assume that equation (10) represents the flow rate in and the flow rate out is equal to 10 mgd, the rate of change of the water volume in the tank is -3.5 sin(6.283 T) mgd. Integrating this expression we find the following equation for the water volume in the tank as a function of time:

$$V(2) = (3.5/6.283)\cos(6.283\,T) + V(2)^* \qquad (13)$$

The value of any cosine function ranges between plus one and minus one with a span of two. The volume of water in the tank must, therefore, vary between some minimum, V(2)*, and that minimum plus 2 x 3.5/6.283 or 1.11 mg.

TIME DEPENDENT ACTIVATED SLUDGE PERFORMANCE
WITHOUT SURGE TANK

One Completely Mixed Tank

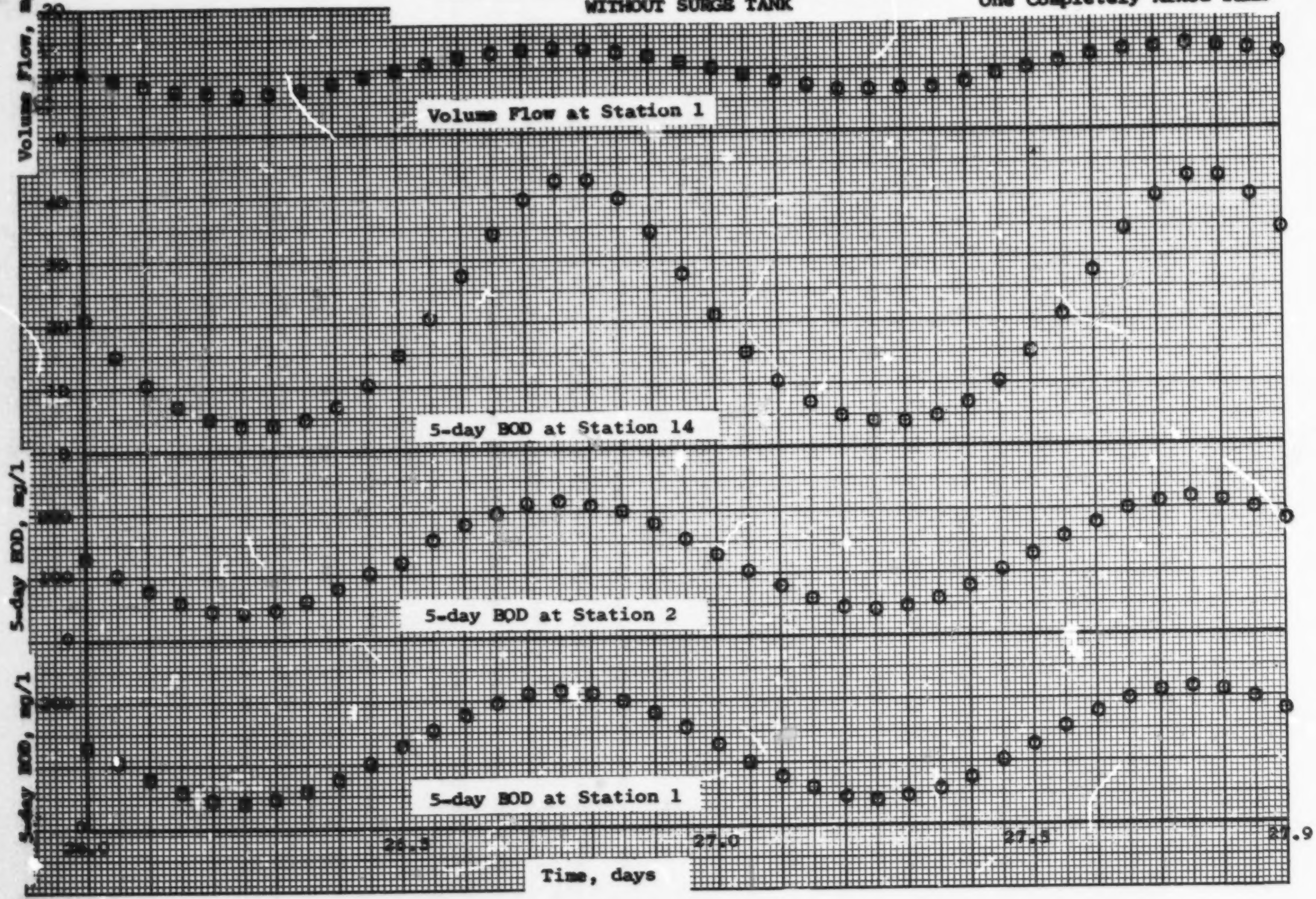


FIGURE 7

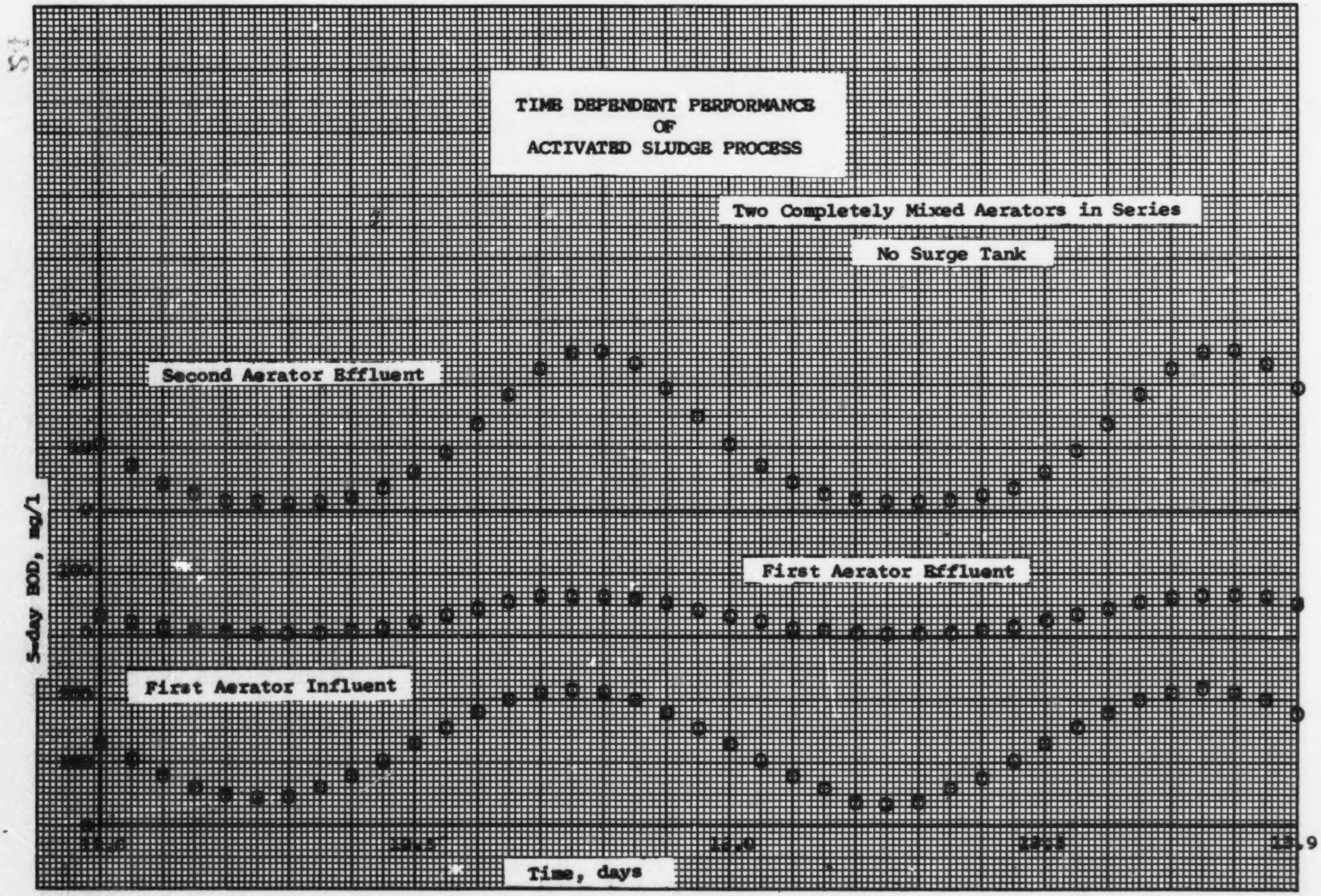

TIME DEPENDENT PERFORMANCE
OF
ACTIVATED SLUDGE PROCESS
Two Completely Mixed Aerators in Series
No Surge Tank
Second Aerator Effluent
First Aerator Effluent
First Aerator Influent
5-day BOD, mg/l
Time, days
13.9

FIGURE 8

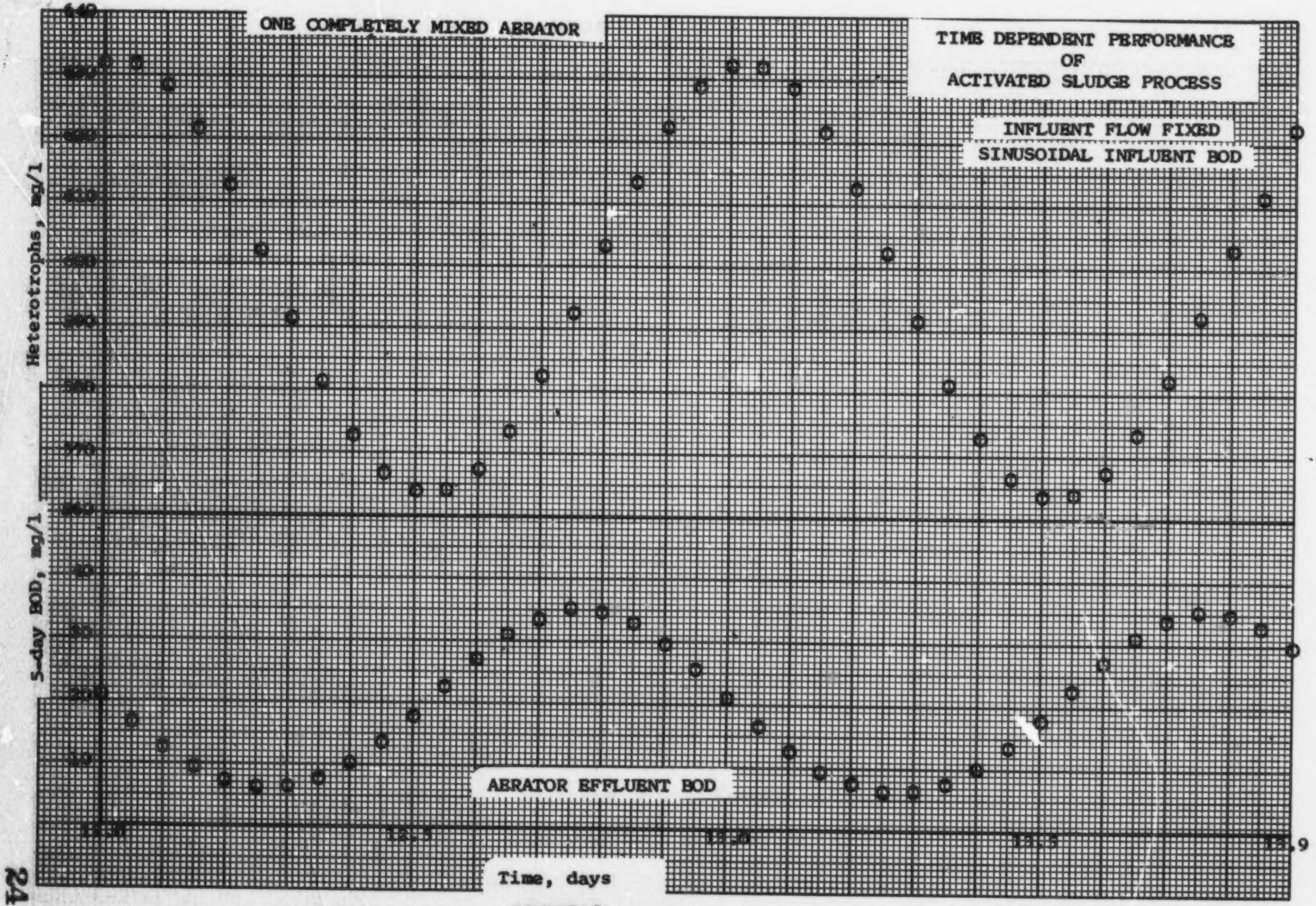

ONE COMPLETELY MIXED AERATOR
TIME DEPENDENT PERFORMANCE
OF
ACTIVATED SLUDGE PROCESS
INFLUENT FLOW FIXED
SINUSOIDAL INFLUENT BOD
Heterotrophs, mg/l
640
5-day BOD, mg/l
40
30
20
10
AERATOR EFFLUENT BOD
12.5
13.9
Time, days

FIGURE 9

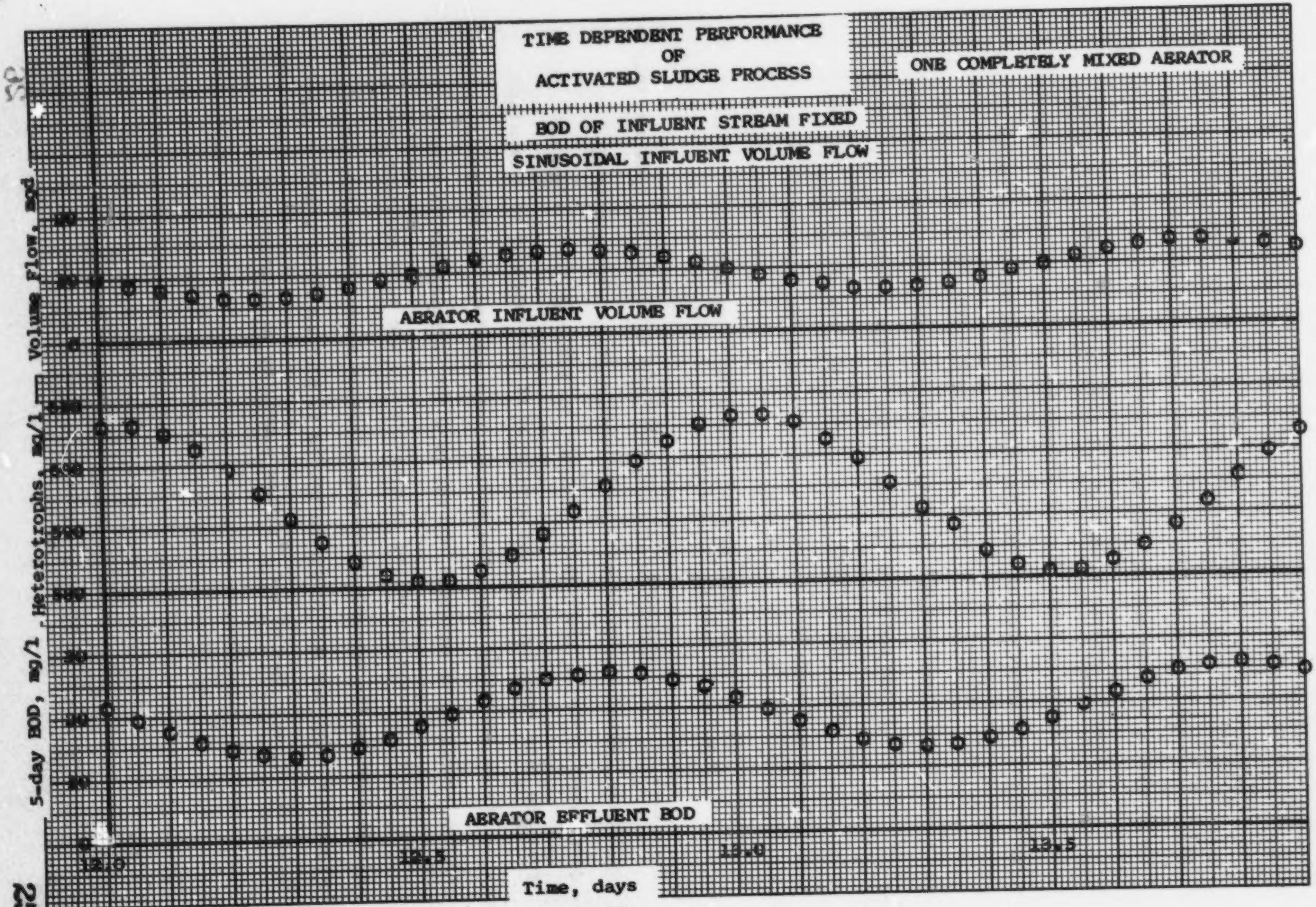

TIME DEPENDENT PERFORMANCE
OF
ACTIVATED SLUDGE PROCESS
ONE COMPLETELY MIXED AERATOR
BOD OF INFLUENT STREAM FIXED
SINUSOIDAL INFLUENT VOLUME FLOW
AERATOR INFLUENT VOLUME FLOW
AERATOR EFFLUENT BOD
5-day BOD, mg/l   Heterotrophs, mg/l   Volume Flow, mgd
40
20
0
30
20
10
0
12.0
12.5
13.0
13.5
Time, days

FIGURE 10

Computed results using an equalization tank are shown in Figures 11 - 14. When $Q_2 = Q_1$, V(2) is set equal to 3 mg. When Q_2 is set at 10 mgd, a V(2) is set at 1.11 mg.

The kinetic constants used in all computations shown in Figures 7 - 14 are given in Table I. The integrated daily discharge of dissolved BOD in the effluent stream (No. 14) for all cases was as follows:

1.	Both BOD and Flow Fixed	1581 lb 5-day BOD/day
2.	Flow Fixed and BOD Varying	1630 lb 5-day BOD/day
3.	BOD Fixed and Flow Varying	1680 lb 5-day BOD/day
4.	BOD and Flow Varying	1950 lb 5-day BOD/day
5.	3 mg Surge Tank with no Pumping $Q_2 = Q_1$	1730 lb 5-day BOD/day
6.	1.11 mg Surge Tank with Pumping to make Q_2 = 10 mgd	1600 lb 5-day BOD/day

From this we might conclude that installing an equalization tank upstream of the activated sludge process could result in a reduction in BOD discharged of about 20%. This, however, is based on the assumption that the rate constant (C_1) for synthesis of heterotrophs is a constant.

If, on the other hand, the maximum rate constant for synthesis varies according to equation (9) the need for an equalization tank will be minimized because according to equation (9) the rate constant increases as the load on the process increases. This is shown graphically in Figure 15 where the BOD in Stream No. 14 is plotted first with a fixed value for C_1 and then with C_1 varying according to equation (9).

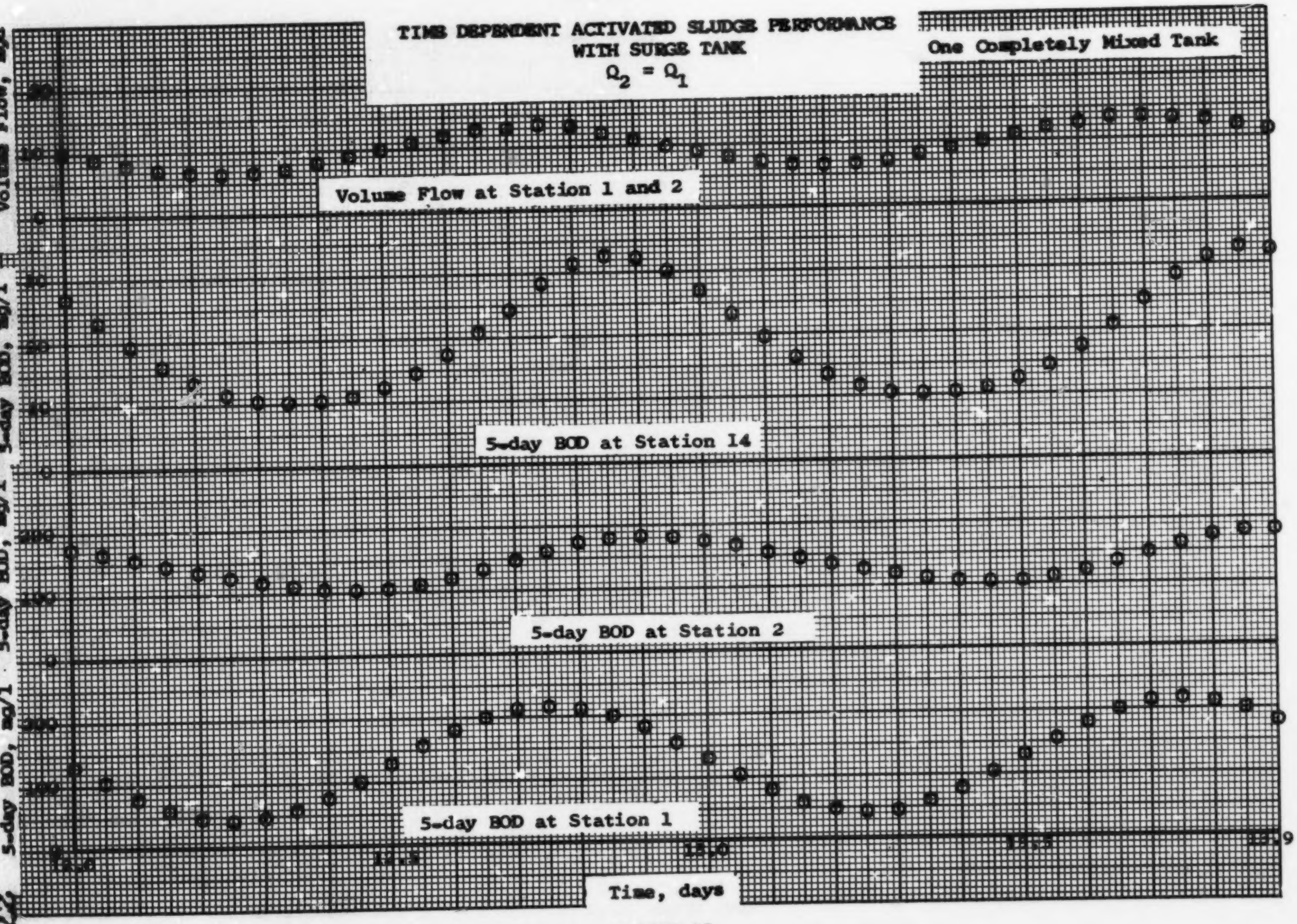
# TIME DEPENDENT ACTIVATED SLUDGE PERFORMANCE
WITH SURGE TANK
$Q_2 = Q_1$

FIGURE 11

TIME DEPENDENT ACTIVATED SLUDGE PERFORMANCE
WITH SURGE TANK
Q_2 = 10 mgd

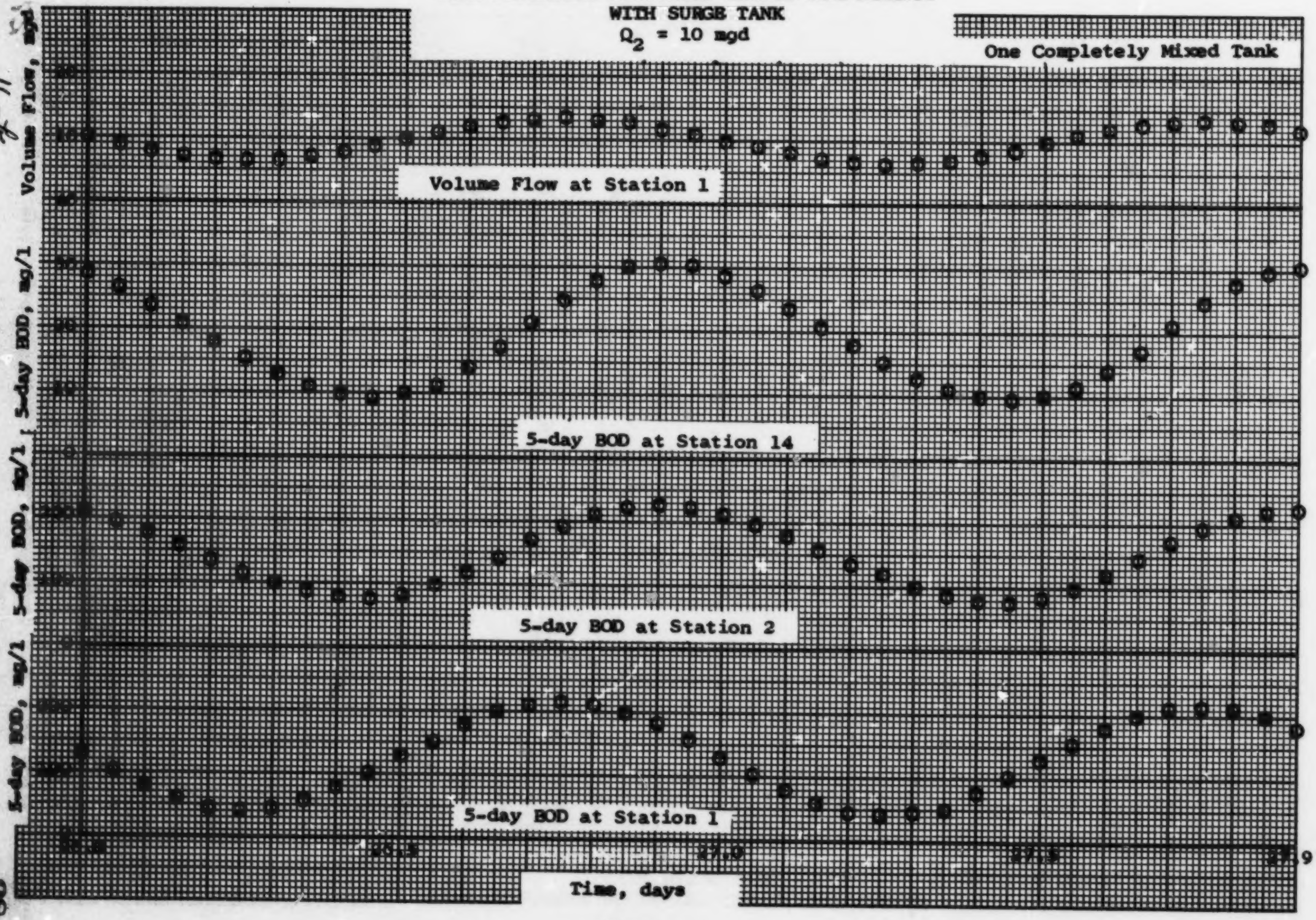


FIGURE 12

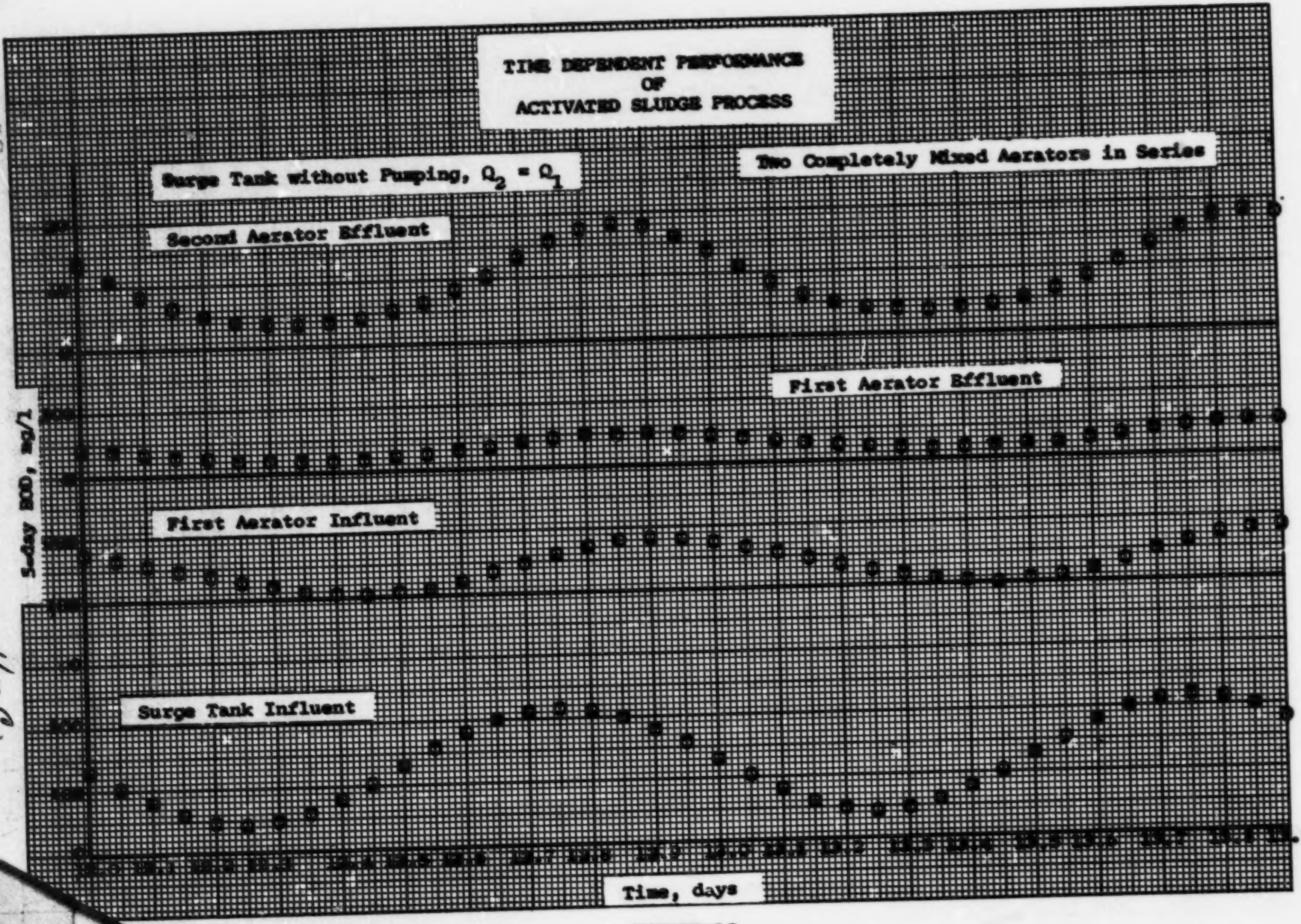


FIGURE 13

16-C

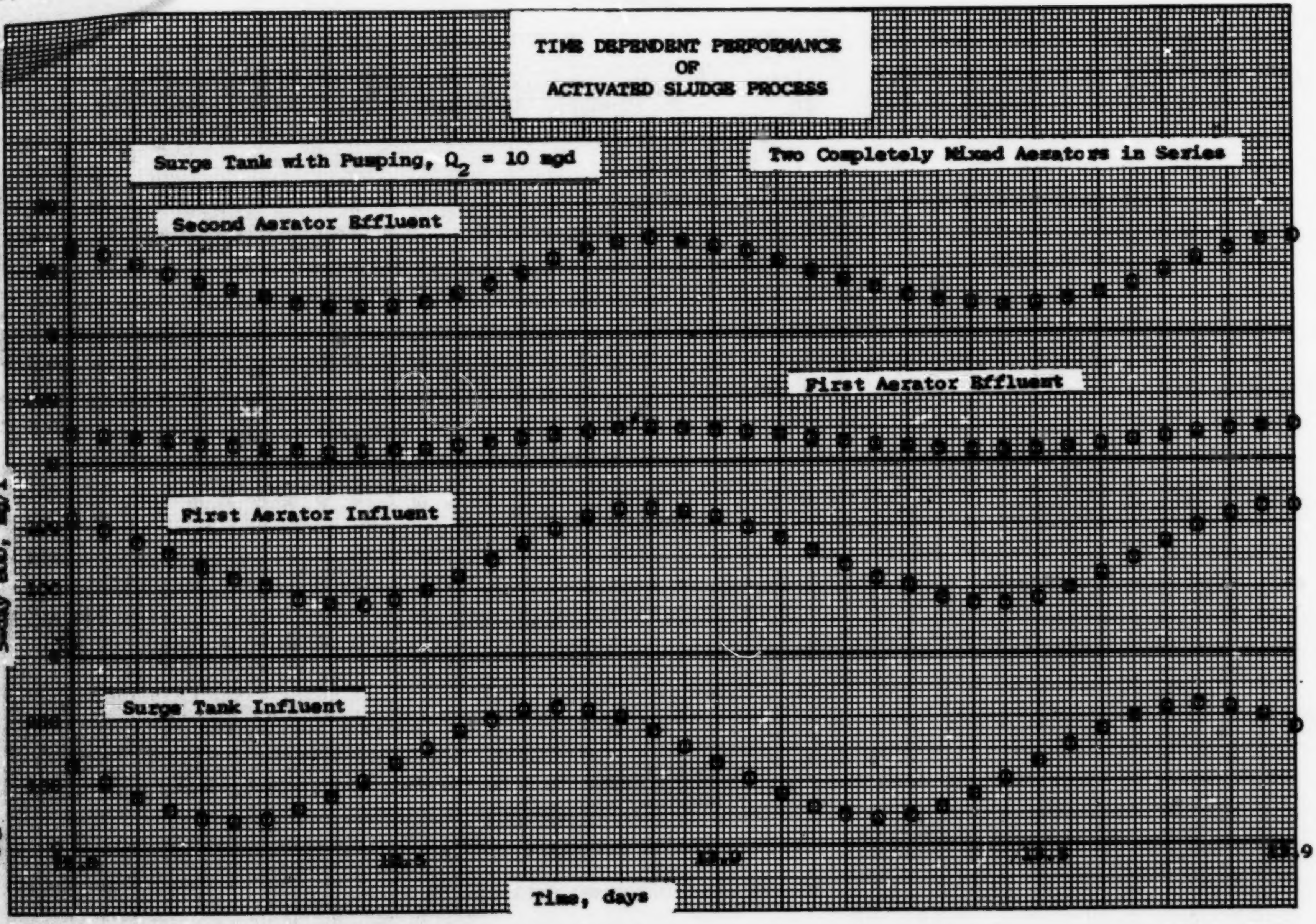
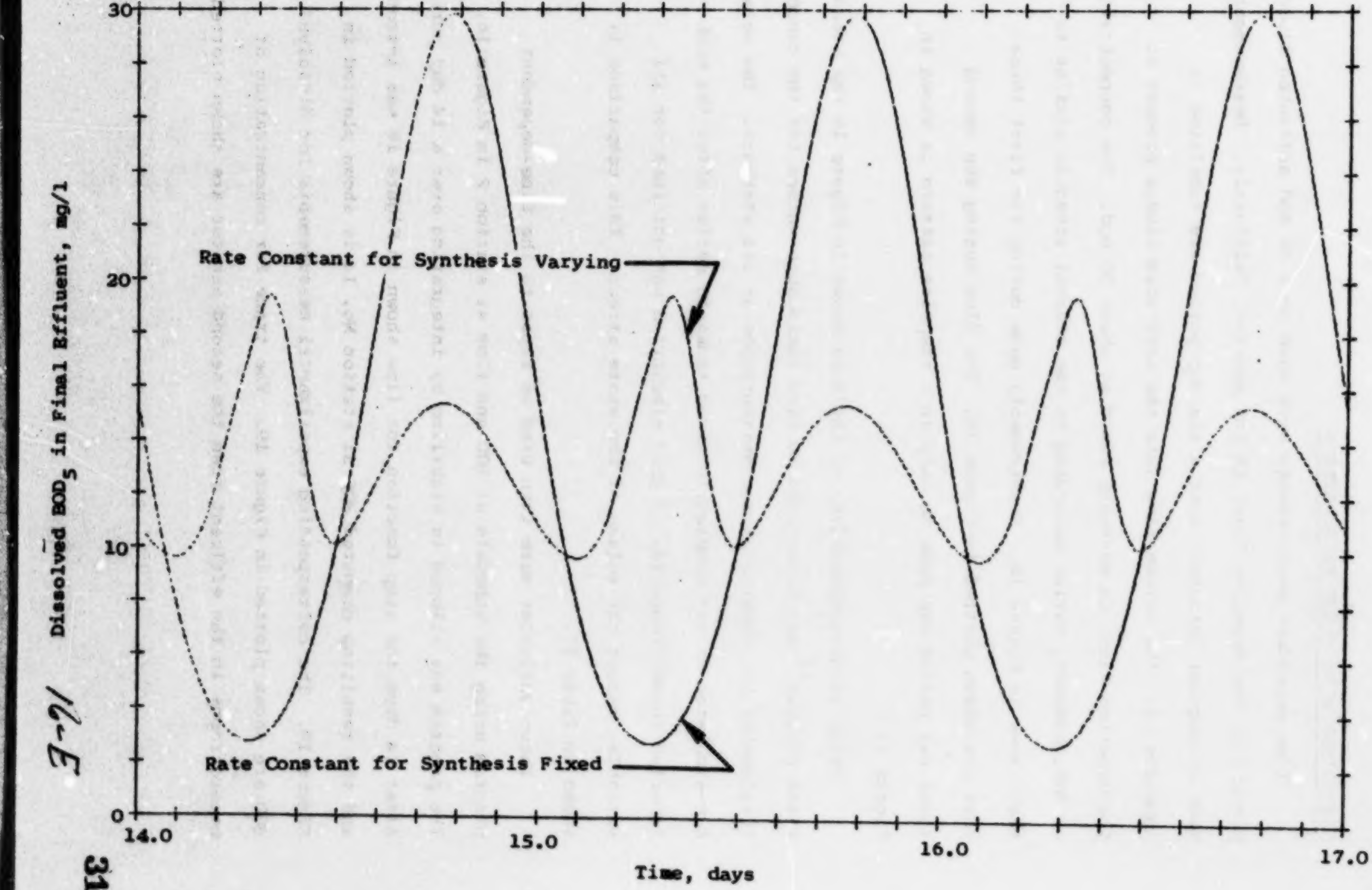


FIGURE 14

16-D

COMPUTER PLOT FROM TIME-DEPENDENT SIMULATION
Sine wave input for Q(1),S(1,1),S(2,1)
Q(15) held fixed



16-E

FIGURE

COMPARISON WITH PLANT MEASUREMENTS

Time-dependent measurements were made on a 50 mgd activated sludge process at the Hyperion Plant in Los Angeles, California. Measurements made at regular intervals over a six day period are tabulated in Appendix II. The volume flow into the activated sludge process at the Hyperion Plant is normally fixed at about 50 mgd. The concentration of BOD, however, varies according to the diurnal schedule similar to that shown in Figure 16. Measurements made during the first three days are shown plotted in Figure 16. The flow during the second three day period was made to vary in a stepwise pattern as shown in Figure 17.

Using 24-hour composites of the data shown in Figure 16 the steady-state program[14] was first used to find reasonable values for the concentrations of all substrates and heterotrophs at all stations. The aerator was simulated as two completely mixed tanks in series after the work reported in Reference 14. A good simulation was obtained for all variables except the volume of the waste stream. This comparison is shown in Table II.

These variables were then used as input to the time-dependent program using the schedule of BOD and flow at station 2 in Figure 16. The program was allowed to stabilize by integrating over a 14 day period. After 14 days the step function for flow shown in Figure 18 was introduced and the resulting computed BOD at station No. 14 is shown plotted in Figure 19. The corresponding experimental measurements for dissolved BOD are shown plotted in Figure 19. The trace for concentration of heterotrophs in the effluent from the second aerator are shown plotted

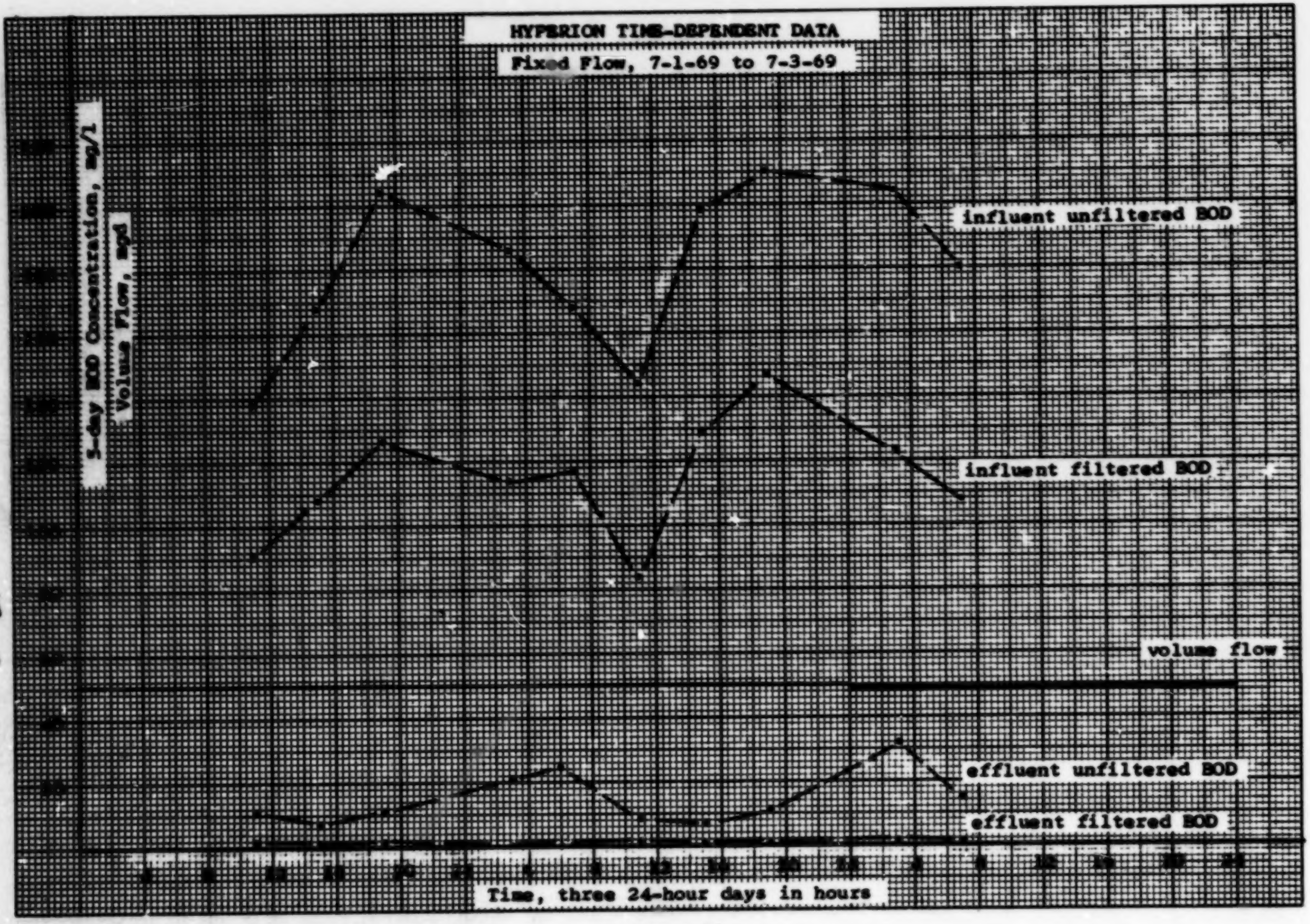


FIGURE 16

17-a

17-8

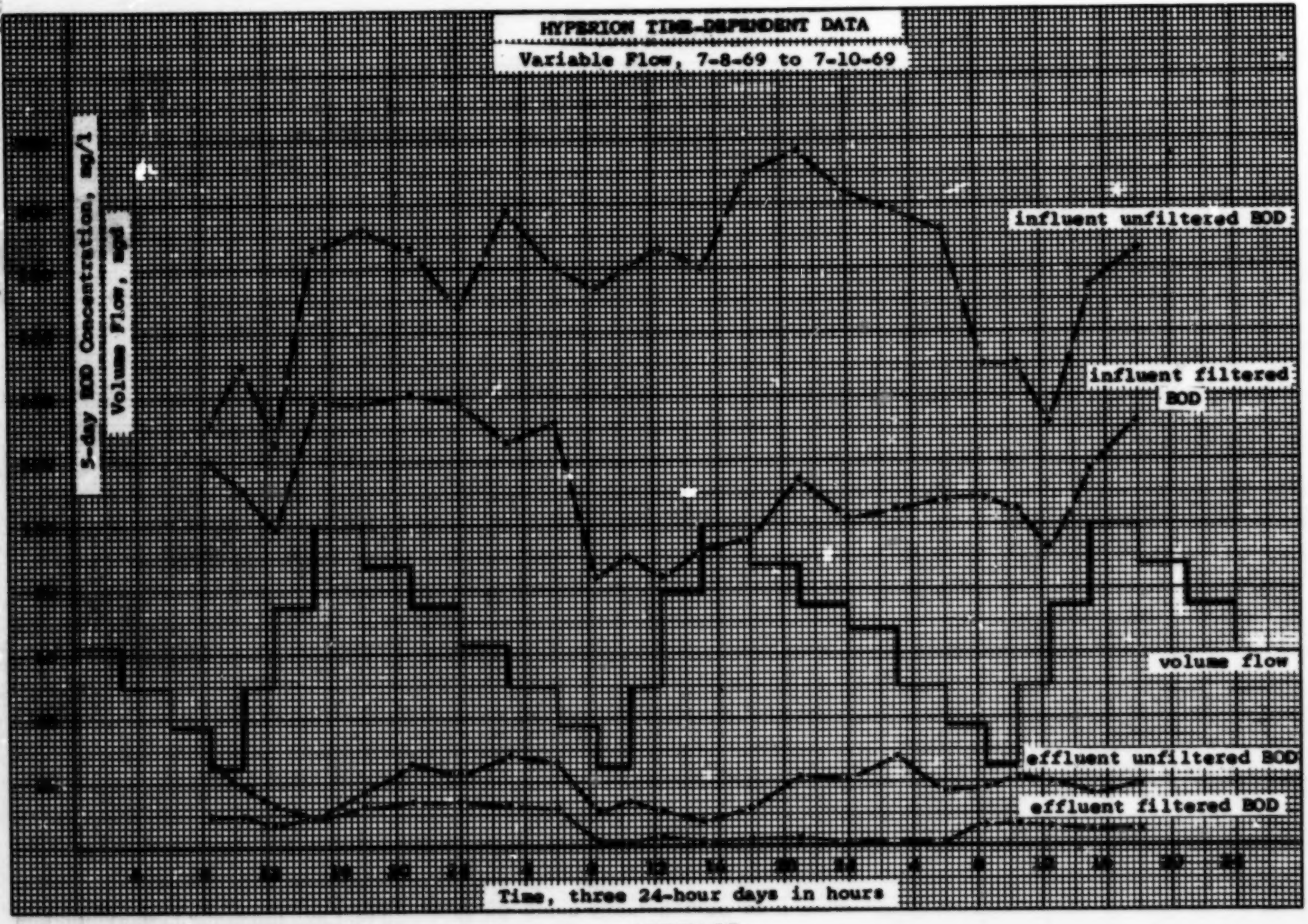


FIGURE 17

TABLE II

STEADY-STATE SIMULATION
OF
HYPERION TIME-DEPENDENT FIXED-FLOW MEASUREMENTS

PARAMETER	MEASURED VALUE	COMPUTED VALUE
Total BOD_5 in Final Effluent, mg/l	7.1	6.2
Dissolved BOD_5 in Final Effluent, mg/l	1.5	2.4
Mixed Liquor Volatile Suspended Solids in the Aerator, mg/l	1381.	1348.
Waste Stream Volume Flow, mgd	.71	1.57
Return Stream Volume Flow, mgd	21.5	20.0

17C

COMPUTER PLOT FROM TIME-DEPENDENT SIMULATION

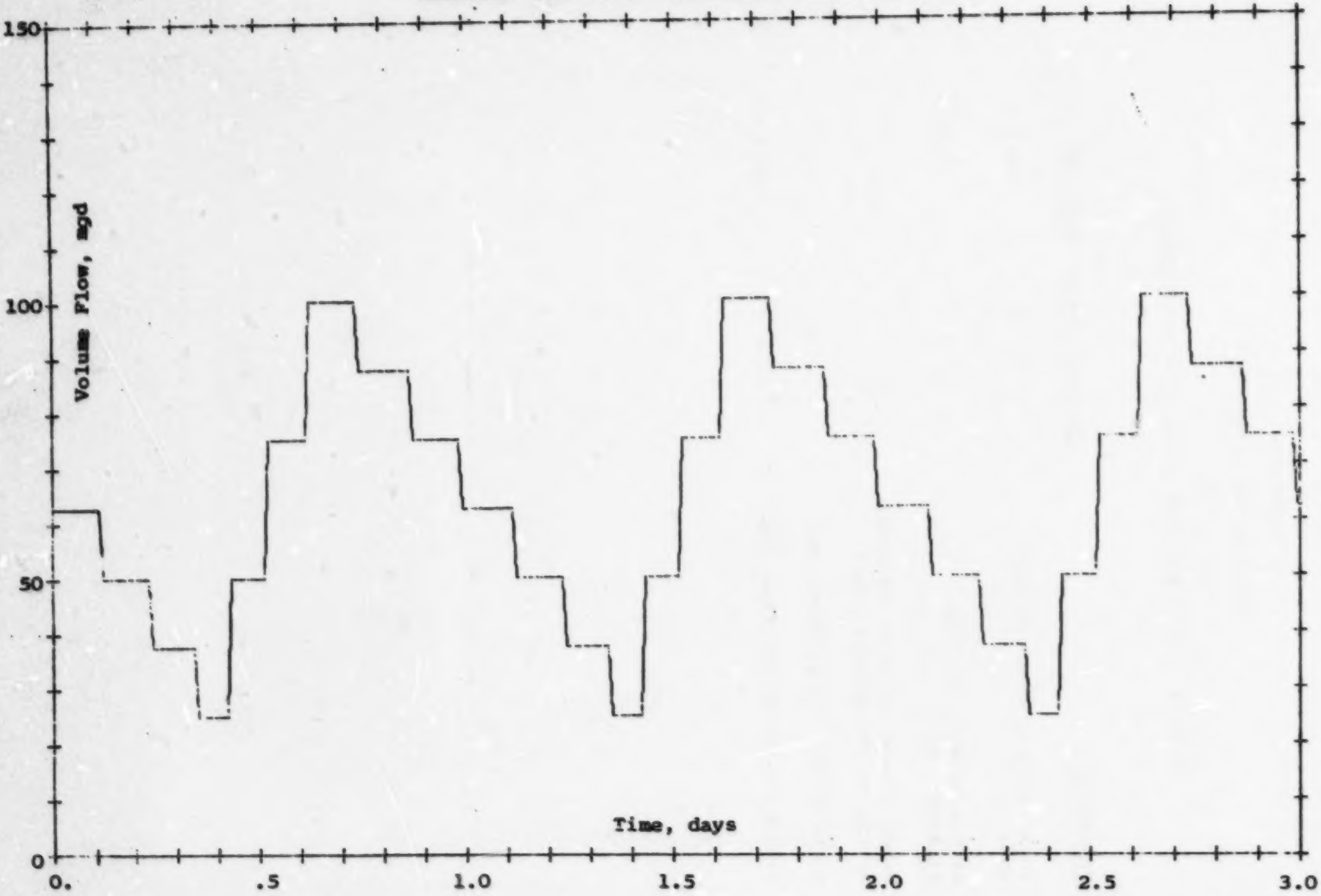


FIGURE 18

COMPUTER PLOT FROM TIME-DEPENDENT SIMULATION

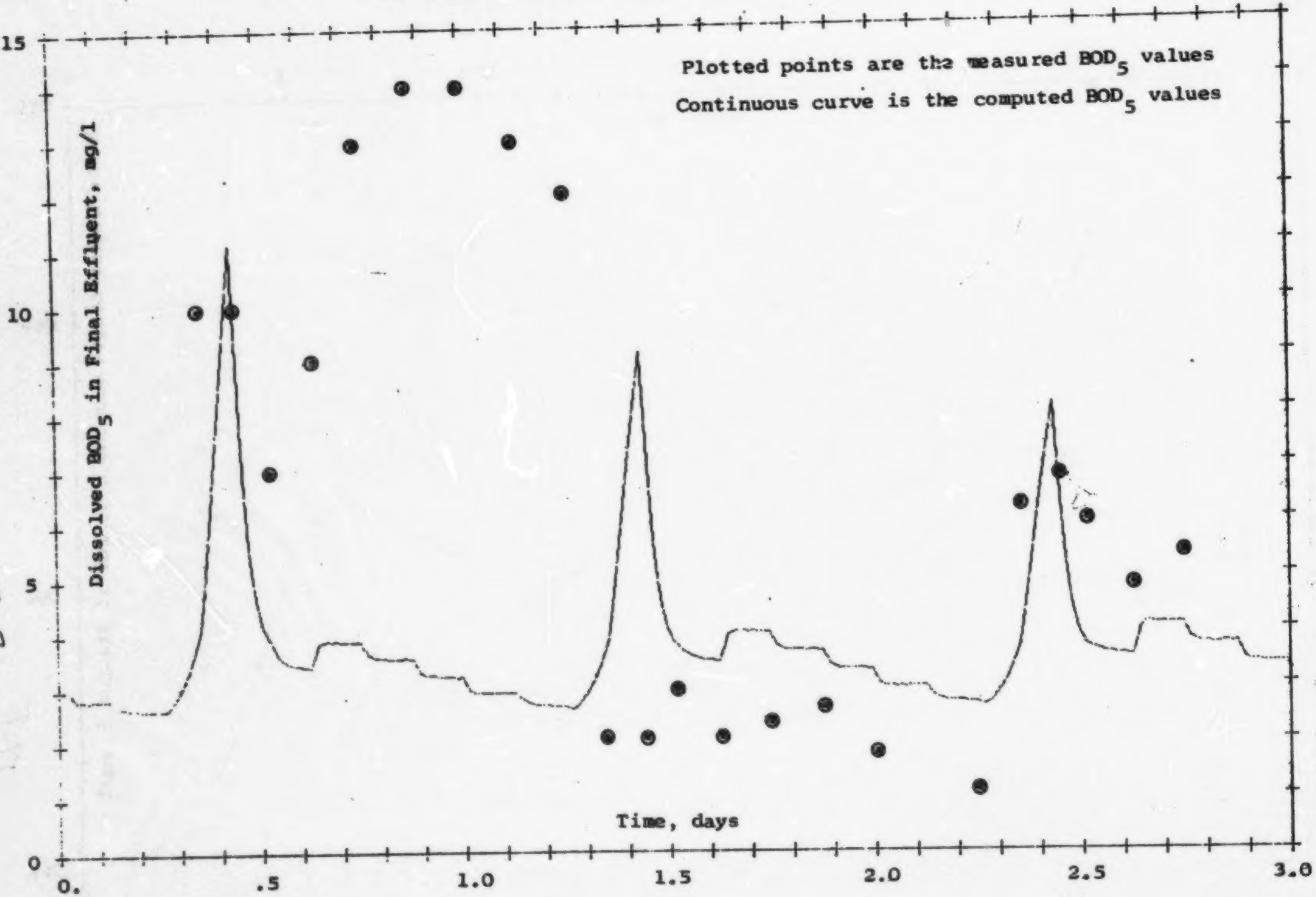
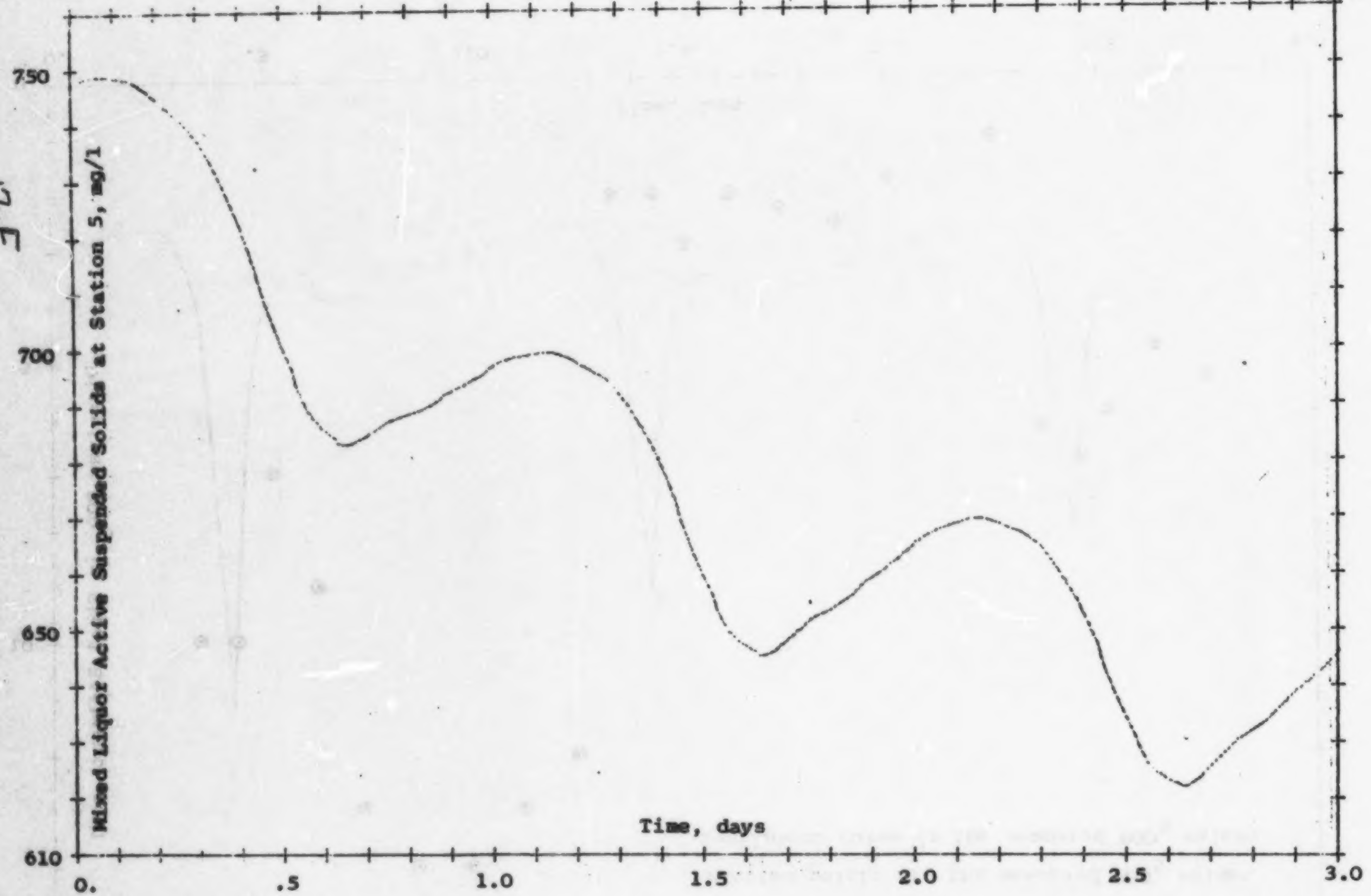


FIGURE 19

COMPUTER PLOT FROM TIME-DEPENDENT SIMULATION



17-F

FIGURE 20

in Figure 20. The volume of the waste stream (No. 15) was held fixed at 1.57 mgd for both computations. The following relationship for C_1 derived from Hyperion results only was used:

$$C_1 = 6.457 - 4.434 \log_e (1/L) \qquad (14)$$

As shown in Figure 19, the correspondence between computed and measured values for BOD in the effluent is scattered. This could be due to deficiencies in the model, inadequate sampling, or both. It does tend to show that a sliding rate constant similar to that shown in equations (9) or (14) may allow a better representation of the kinetics of the process than a fixed rate constant. These results are clearly inconclusive and much more work is needed before the time-dependent performance of the process can be reliably represented by mathematical relationships.

STUDIES OF POSSIBLE CONTROL MODES

The program has been used to quantify the advantages to be gained by installing various kinds of control in the activated sludge process. A fixed rate constant for synthesis (C_1) has been used in every case, because it is known that the response of the process to varying loads is maximized when the rate constant (C_1) is held fixed instead of being allowed to vary with loading as represented by equations (9) or (14).

The results of installing an equalization tank upstream of the process has already been given on page 15. The next control measure tried was scheduling of the waste activated sludge stream (No. 15) volume in a sinusoidal manner. The relationship used for scheduling the waste activated sludge stream is given as follows:

```
Q(15) = B - A*SIN(6.283*(T - TLAG))
```

In this equation A was set equal to B so that the volume of the waste stream varied from a minimum of zero to twice the steady-state value of B. Using a two tank aerator with a detention time of four hours and a fixed volume flow for the wate stream it was found that the BOD discharged was 1380.6 lb/day. By scheduling the waste stream sinusoidally this was reduced to 1368.8 lb/day or only about 1%. The greatest reduction in BOD discharged (1%) was found when the waste stream was scheduled <u>in phase</u> with the applied load.

The use of a sludge storage tank for returning greater quantities of sludge to the aerator during high load conditions was investigated in some detail. An equation similar to the one for scheduling Q(15) was used to control the sludge return stream Q(17). It was found that considerable improvement, in process efficiency, could be effected by returning sludge from the storage tank sinusoidally in phase with the loading imposed at station No. 2. For example, using four hours detention in the aerator and a sludge storage tank of equal volume (1.667 mg) the amount of BOD discharged with no scheduling, $Q_{17} = Q_{16}$, was 1680 lb/day. The flow through the sludge storage tank was 2.3 mgd. By varying the flow from the sludge storage tank in phase with the influent load the amount of BOD discharged was cut to 1428 lb/day. The volume of the waste stream was held fixed at 0.15 mgd. This represents a 15% improvement in the amount of BOD discharged from the process.

It was noted, however, that as a result of this control measure the concentration of active solids in the aerator and return tank had increased significantly. The question arising out of this result was whether the same result could have been obtained by reducing the volume of the waste stream and increasing the concentration of active solids in the system with no control of return sludge. This question was studied by computing the performance with and without scheduling at various active solids concentrations and plotting the results as shown in Figure 21. The amount of improvement which can be attributed to scheduling alone was then found to be about 2% for the one tank aerator and only about 1% for the two tank aerator.

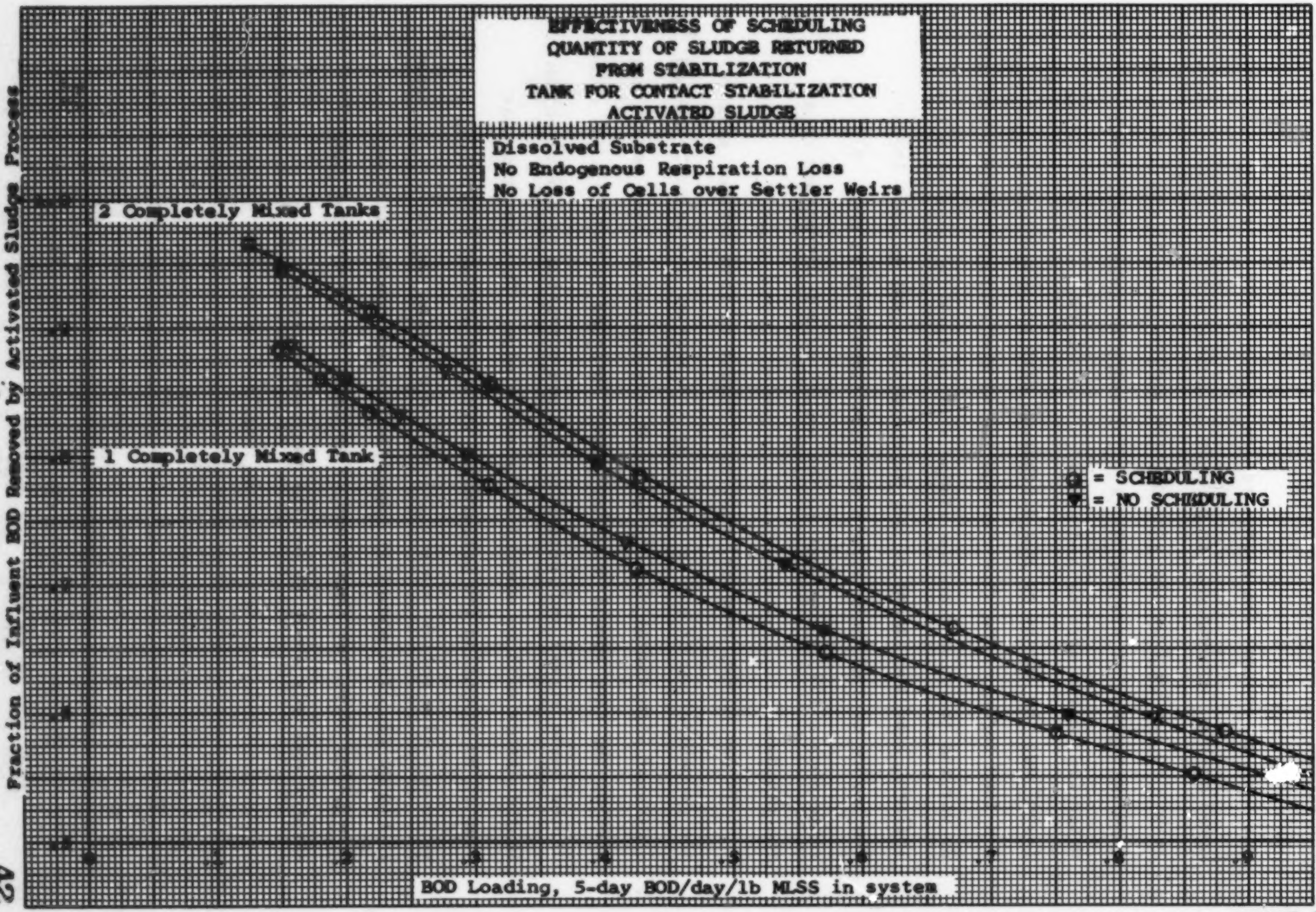

EFFECTIVENESS OF SCHEDULING
QUANTITY OF SLUDGE RETURNED
FROM STABILIZATION
TANK FOR CONTACT STABILIZATION
ACTIVATED SLUDGE
Dissolved Substrate
No Endogenous Respiration Loss
No Loss of Cells over Settler Weirs
2 Completely Mixed Tanks
1 Completely Mixed Tank
○ = SCHEDULING
▼ = NO SCHEDULING
Fraction of Influent BOD Removed by Activated Sludge Process
BOD Loading, 5-day BOD/day/lb MLSS in system
0
.1
.2
.3
.4
.5
.6
.7
.8
.9

FIGURE 21

CONCLUSIONS AND RECOMMENDATIONS

A digital computer program has been developed which simulates the time-dependent performance of the activated sludge process. The program assumes that the substrate is dissolved and that the fraction of suspended solids which escape over the final settler weirs is a fixed percentage of the solids entering the final settler. The compaction ratio, URSS, is taken as a constant. The lack of adequate mathematical relationships for representing the performance of the final settler is a significant weakness of the model.

The rate constant for synthesis has been assumed to be a constant and to vary with the loading. The relationship which varies the rate constant with loading was derived from steady-state measurements. The true relationship between rate of synthesis and other process variables which will apply to time-dependent performance is not known.

The opportunities for improving the process performance through control appears to be greatest when the rate of synthesis is a true constant. The intrinsic improvement in process performance through scheduling the volume of the waste activated sludge stream or the volume of the return stream from the sludge storage tank appears to be small. A significant improvement does appear to be possible through use of an equalization tank upstream of the process when the pumping rate out of the equalization tank is held fixed.

Validation of the model is less than adequate, but in view of the limited possibilities for process improvement through control, additional work towards validation of the model may not be justified.

HOW TO USE THE PROGRAM

The time-dependent program can simulate up to 10 sub-volume aerators in series and compute the kinetic behavior of three classes of bacteria -- BOD users, nitrosomonas and nitrobacter. The effect of a surge tank on the system can be simulated by setting the input value of V(2) equal to the volume of the surge tank. The effect of a stabilization tank in the return line can also be simulated by setting the input value of V(17) equal to the volume of the return tank. Logic has been included in the program to prevent any of the system variables from going negative, and the program can never get caught in a loop.

There are several ways of controlling the volume flow, Q(1), into the system in order to observe its effect on performance. First of all , Q(1) can be held constant; for example, set Q(1) = 10 mgd. Q(1) can also be allowed to vary sinusoidally with respect to time; for example, by setting Q(1) = 10. - 3.*SIN(6.283*T), Q(1) will vary between 7 and 13 mgd as T(time) continually increases. Q(1) can also vary as step function input. Since it has been found that an integration interval of H = .01 day produces adequate results from the program, the Q(1) for one day can be divided up into 100 step values and input to the program by means of a matrix. At the start of the second day calculations, the 100 matrix values are used over again, etc. This step method of input was used to simulate the time-dependent data that was gathered at the Hyperion plant in Los Angeles. Q(1), S(1,1) and URSS were used by the program as step input from 100 values supplied for each by means of matrix input.

The influent substrate concentrations can also be varied in different ways to study their effect on the performance of the system. S(1,1), the 5-day BOD concentration at station 1, and S(2,1), the ammonia concentration at station 1, can be held constant; for example, by setting S(1,1) = 130 mg/l and S(2,1) = 30 mg/l. The concentrations may also be allowed to vary sinusoidally with respect to time; for example, by setting S(1,1) = 130. - 90*SIN(6.283*T) and S(2,1) = 30. - 20.*SIN(6.283*T), S(1,1) will vary between 40 and 220 mg/l and S(2,1) will vary between 10 and 50 mg/l as T continually increases. The concentrations can also be supplied to the program as step input in matrix form in the same way that Q(1) is supplied to the program as step input.

It has been noticed that URSS, the final settler compaction ratio, can also vary significantly. This was observed while studying the time-dependent data taken at the Hyperion plant. For this reason, URSS, which is usually read into the program as an input constant, can be allowed to vary as a step function by supplying an input matrix to the program in the same way that Q(1) is supplied to the program as step input.

The volume of the waste stream, Q(15), may be read into the program as a constant, such as Q(15) = .25 mgd, or may be allowed to vary sinusoidally with respect to time, such as by setting Q(15) = .25 - AMP*SIN(6.283*(T - TLAG)). The volume of the return stream, Q(17), may also be allowed to vary sinusoidally with respect to time, such as by setting Q(17) = 2. - AMP*SIN(6.283*(T - TLAG)). AMP and TLAG are read into the program as input. AMP is the desired amplitude of the variation, and TLAG is used to cause the variation to be out of phase with the sine variation of other variables in the system. If TLAG is set equal to 0, then the sine variation is in phase with the other variables in the system. The amount of phase variation does have an effect on the performance of the system.

Unfortunately, all of the versatility that may be used in varying these important system variables cannot be easily built into a single program. The time-dependent card deck has to be altered to permit the various system setups that have been discussed. That is, however, not very difficult; by changing a few of the FORTRAN statements, which specify how Q(1), S(1,1), S(2,1), URSS, Q(15) and Q(17) are determined, one can easily get the program to run a particular case. The FORTRAN listing of the program that appears in Appendix I is setup to run by reading in 100 step input matrix values for each of three variables -- S(1,1), Q(1), and URSS. This is how the program was used to simulate time-dependent performance based on the Hyperion data. The cards that are marked on the listing can be removed and substituted with constants or sine wave equations as indicated.

Since it is possible to generate a great deal of printed output from this program, several controls were built into it to limit the amount of printing that need be done. For example, suppose a time-dependent simulation is to be run out to 15 days in order for the system to settle down to steady-state. The user can eliminate the printout associated with the first 14 days by setting TD = 14 on input. The program will then only print the output for the 15th day. The amount of program printout can also be cut down by setting NCALC equal to the number of increment calculations not to be printed between each print instruction; for example, setting NCALC = 10 will cause the program to only print every 10th calculation that it makes.

XXX (accumulated BOD at station 14 for one day, lbs), YYY (BOD removal at station 14 for one day, lbs) and ZZZ (BOD loading at station 14 for one day, lbs) all represent a delta change of one day; that is, every time they are printed, each is equal to the total change in lbs since the corresponding time 24-hours earlier. In order to calculate XXX, YYY and ZZZ properly for a particular input value of H, the program deck may need to be altered. The deck is setup to calculate these variables based on an integration interval of H = .01. If the user desires to input a different value for H, then statement number 650 of the program deck must be changed as indicated on the FORTRAN listing of the program in Appendix I.

The maximum rate constant for synthesis of the BOD users, C1(1), can be read into the program as an input constant. The program, however, contains a relationship which determines C1(1) uniquely for each time increment calculation based on inverse loading (lb mixed liquor active suspended solids/lb BOD) on the system at that time increment. This value of the rate constant is then adjusted based on the water temperature. The program listing, as it appears in Appendix I, is setup to calculate C1(1) from the relationship, and these values over-ride the input value.

When the time-dependent simulation is such that the various stations from 5 to 13 (cf. Figure 1) are not needed, such as in the simulation of a one tank system, X(I,J) and S(I,J) values at these stations are not supplied as input to the program.

The time-dependent model was programmed in FORTRAN for the IBM 1130 computer. In order to get an idea of the program running time, consider a 15 day simulation with only the time increment calculations from the 14th to the 15th day printed out with H = .01. It will take about 10 minutes of IBM 1130 execution time to run this simulation. As would be expected, a great deal of program printout increases the execution time considerably.

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APPENDIX I

LISTING AND OPERATING INSTRUCTIONS FOR THE TIME-DEPENDENT PROGRAM

INPUT DATA TO THE TIME-DEPENDENT PROGRAM

```
Input Card 1:  FORMAT(I10,5F10.3,I10)
               N, H, T, TD, TLAG, AMP, NCALC

Input Card 2:  FORMAT(I10,6F10.3,F10.4)
               NTKS, VABR, V(2), V(17), CTEMP, Q(15), URSS, XRSS

Input Card 3, 4, 5:  FORMAT(4F10.3)
                     (C1(I), C2(I), C3(I), C4(I), I = 1,3)

Input Card 6:  FORMAT(3F10.3)
               (S(I,2), I = 1,3)

Input Cards 7 up to 16:  FORMAT(3F10.3)
                         ((X(I,J), I = 1,3), J = 4,K)

Input Cards 17 up to 26:  FORMAT(3F10.3)
                          ((S(I,J), I = 1,3), J = 4,K)

Input Card 27:  FORMAT(3F10.3)
                (X(I,17), I = 1,3)

Input Card 28:  FORMAT(3F10.3)
                (S(I,17), I = 1,3)
```

Figure I-1 gives an example of the card input form for the program

Figure I-2 gives the flowchart for the program

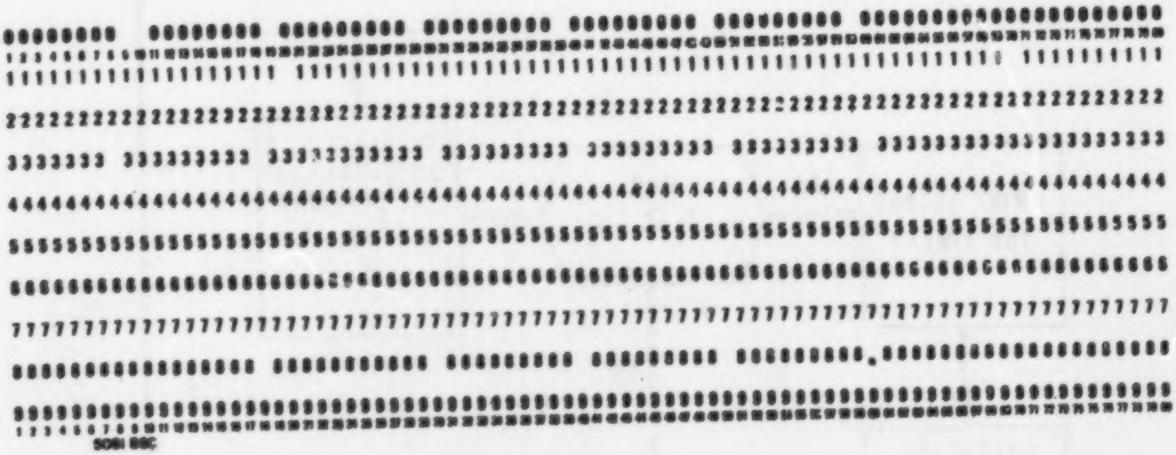
Figure I-3 gives definitions of the FORTRAN variables used by the program

Figure I-4 gives a sample of step input to the program

Figure I-5 gives the FORTRAN listing of the program

Figure I-6 gives a partial printout from the program

```
3.6        .76        17.8
2380.      28.5       0.
3.6        .76        17.8
20.3       5.1        13.4
747.       8.9        0.
742.       8.7        0.
112.       18.        .08
      1.         2.1        .18        .02
      .68        1.         0.         .05
      6.4        150.       .167       .55
      2          12.5       0.         0.        26.39      1.53      3.48      .0112
      300        .01        0.         0.        0.         0.        1
```



Sample Input Deck for the Time-Dependent Program

FIGURE I-1

Reproduced from
best available copy.

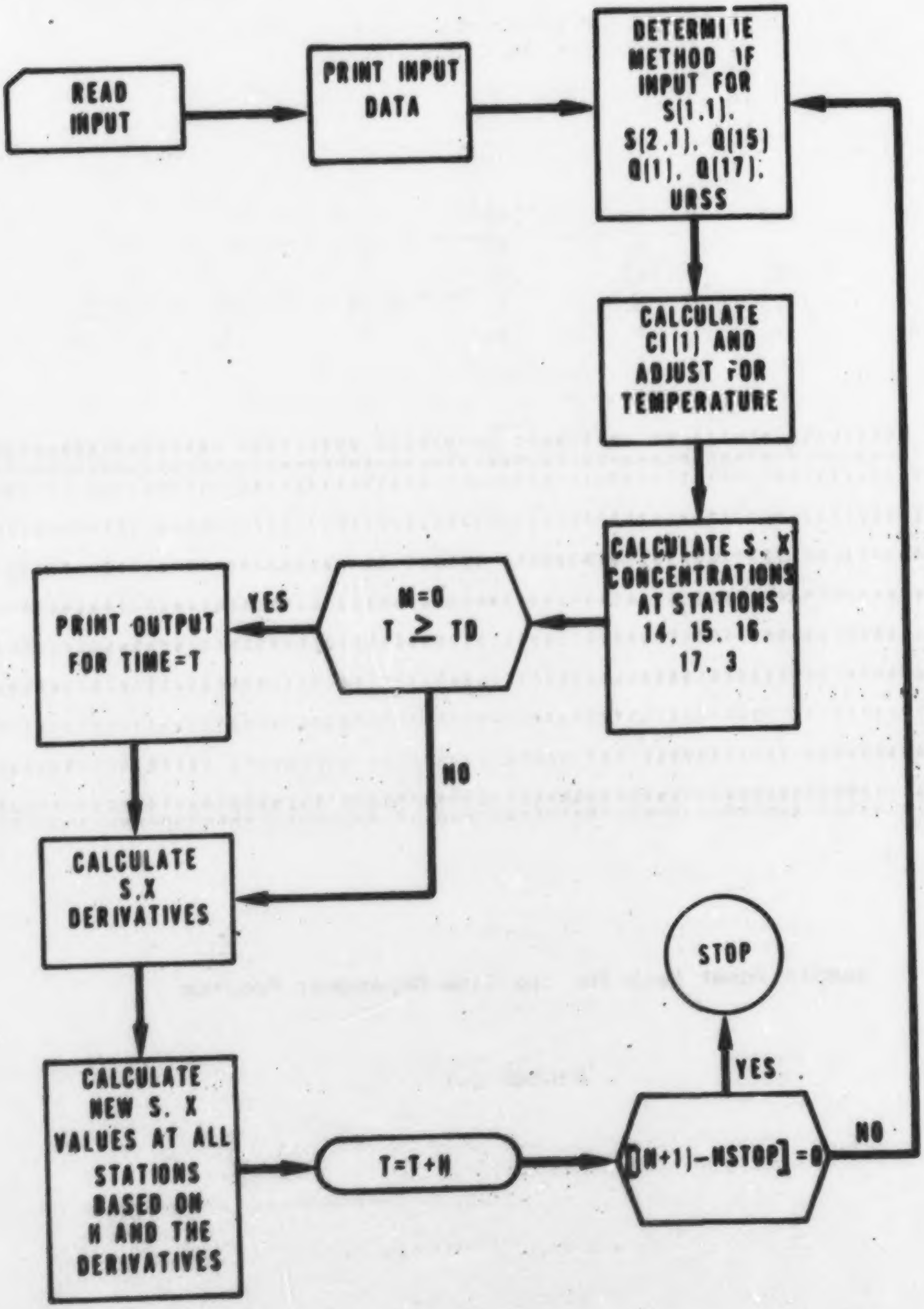

READ INPUT
PRINT INPUT DATA
DETERMINE METHOD OF INPUT FOR S(1,1), S(2,1), Q(15) Q(1), Q(17), URSS
CALCULATE CI(1) AND ADJUST FOR TEMPERATURE
CALCULATE S, X CONCENTRATIONS AT STATIONS 14, 15, 16, 17, 3
N=0 T ≥ TD
YES
NO
PRINT OUTPUT FOR TIME=T
CALCULATE S,X DERIVATIVES
CALCULATE NEW S, X VALUES AT ALL STATIONS BASED ON H AND THE DERIVATIVES
T=T+H
[(N+1)−NSTOP]=0
YES
NO
STOP

FIGURE I-2

FIGURE I-3

DEFINITIONS OF FORTRAN SYMBOLS FOR THE TIME-DEPENDENT PROGRAM

Computer Symbol	Definitions and Comments
AMP	The amplitude of sine wave variations for program inputs
C1(I)	Maximum rate constant for synthesis, day^{-1}: I = 1 for heterotrophs, I = 2 for nitrosomonas, I = 3 for nitrobacter. The program calculates C1(1) for each time increment based on inverse loading and water temperature, or it can be left equal to the input value by altering the program deck.
C2(I)	Saturation constant, mg/l of substrate: I = 1 for heterotrophs, I = 2 for nitrosomonas, I = 3 for nitrobacter
C3(I)	Endogenous respiration constant, fraction of viable cells which lyse per day: I = 1 for heterotrophs, I = 2 for nitrosomonas. I = 3 for nitrobacter.
C4(I)	Yield coefficient, lbs cells synthesized per lb of substrate utilized: I = 1 for heterotrophs, I = 2 for nitrosomonas, I = 3 for nitrobacter.
CTEMP	Water temperature, °C
H	Time increment between calculations, days. An increment of .01 of a day is usually small enough.
K	Set equal to (NTKS+1) by the program
N	Number of H-size time increments for the program to calculate
NCALC	Program control: the program will only print out every NCALCth calculation the program makes. If it is set equal to 1, every calculation in printed out.
NTKS	Number of equal volume sub-aerators
Q(I)	Volume flow at station I, mgd

DEFINITIONS OF FORTRAN SYMBOLS FOR THE TIME-DEPENDANT PROGRAM

Computer Symbol	Definitions and Comments
S(I,J)	Concentration of substrate at station J, mg/l: I = 1 for 5-day BOD, I = 2 for ammonia, I = 3 for nitrate
T	Starting time of the first calculation
TD	Program control: the program will only begin to print out calculations at the time specified by this input value; if TD is set equal to 0, all of the calculations will be printed out.
URSS	Final settler compaction ratio
V(I)	Volume of individual sub-aerators, millions of gallons. V(2), the surge tank volume, and V(17), the return tank volume, are read into the program as input.
VAER	Total volume of aerator, millions of gallons
X(I,J)	Concentration of microorganisms at station J, mg/l: I = 1 for heterotrophs, I = 2 for nitrosomonas, I = 3 for nitrobacter
XRSS	Final settler efficiency
XXL	Inverse 5-day BOD loading, 1./(lb 5-day BOD per day per lb MLASS)
XXX(I)	Accumulated BOD at station 14 for one day, lbs
YYY(I)	BOD removal at station 14 for one day, lbs
ZZZ(I)	BOD loading at station 14 for one day, lbs

FIGURE I-4

130.000	129.500	129.000	128.500	128.500	128.000	128.000	127.500	127.000	127.000
126.500	126.500	126.000	126.000	126.500	127.000	127.500	128.000	128.500	129.000
129.500	130.000	130.500	131.000	131.500	132.000	127.000	122.000	117.000	112.000
107.000	102.000	97.000	92.000	88.000	84.000	84.500	85.000	86.000	87.000
87.500	88.000	89.000	89.500	90.000	89.500	89.000	88.000	87.500	87.000
86.000	85.500	85.000	86.000	86.500	87.000	88.000	89.000	89.500	90.000
91.000	92.000	93.000	93.000	93.500	93.500	94.000	94.000	94.500	94.500
95.000	95.000	95.500	95.500	95.500	96.000	97.000	98.500	100.000	101.000
102.500	104.000	106.000	107.000	108.000	110.000	111.500	113.000	115.000	116.000
117.000	118.000	119.500	121.000	122.000	123.000	124.000	126.000	127.000	129.000
62.500	62.500	62.500	62.500	62.500	62.500	62.500	62.500	62.500	62.500
62.500	62.500	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000
50.000	50.000	50.000	50.000	37.500	37.500	37.500	37.500	37.500	37.500
37.500	37.500	37.500	37.500	37.500	25.000	25.000	25.000	25.000	25.000
25.000	25.000	25.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000
50.000	50.000	75.000	75.000	75.000	75.000	75.000	75.000	75.000	75.000
75.000	75.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
100.000	100.000	100.000	100.000	87.500	87.500	87.500	87.500	87.500	87.500
87.500	87.500	87.500	87.500	87.500	87.500	87.500	75.000	75.000	75.000
75.000	75.000	75.000	75.000	75.000	75.000	75.000	75.000	75.000	62.500
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Step Input Used to Simulate the Hyperion Time-Dependent Data

Rows 1 - 10 are the S(1,1) values

Rows 11 - 20 are the Q(1) values

Rows 21 - 30 are the URSS values

TIME DEPENDENT PLOT PROGRAM

```
TD=0.
CALL SCALF (3.,.04,TD,0.)
CALL FGRID (0,TD,0.,.1,30)
CALL FGRID (1,(TD+3.),0.,10.,15)
CALL FGRID (2,(TD+3.),150.,.1,30)
CALL FGRID (3,TD,150.,10.,15)
CALL FPLOT (3,TD,0.)
CALL EXIT
END
```

Plotter logic which can be removed or replaced

FIGURE I-5

```
C     THIS DECK USES BRUTE FORCE NUMERICAL INTEGRATION
      DIMENSION X(3,17),S(3,17),Q(17),V(17),C1(3),C2(3),C3(3),C4(3),
     . DELS(3,17),DELX(3,17),DLS17(3),DLX17(3),XXX(100),YYY(100),
     . ZZZ(100),SMATX(100),QMATX(100),UMATX(100)
      DATA X/51*0.0/,S/51*0.0/,Q/17*0.0/,V/17*0.0/
      DATA C1/3*0.0/,C2/3*0.0/,C3/3*0.0/,C4/3*0.0/
      DATA XXX,YYY,ZZZ,Y,XREM,XLOAD/303*0.0/
      DATA ICNT,M,III/2*0,1/
      DS17F(A,B,C,D,E,F)=(Q16*A-Q17*B)/V17-C*B*D/(E+B)/F
      DSDTF(A,B,C,D,E,F,G)=Q3*(A-B)/C-D*B*E/(F+B)/G
      DXDTF(A,B,C,D,E,F,G)=Q3*(A-B)/C+D*B*E/(F+E)-G*B
      DX17F(A,B,C,D,E,F)=(Q16*A-Q17*B)/V17+C*B*D/(E+D)
      IN=2
      IO=5
      IP=7               Plotter logic which can be removed
  101 FORMAT(10F8.2)
  102 FORMAT(I10,5F10.3,I10)
  103 FORMAT(3F10.3)
  104 FORMAT(4F10.3)
  105 FORMAT(5X,32HACCUMULATED BOD AT STATION 14 = ,E11.5,2X,2HLB)
  106 FORMAT(I10,6F10.3,F10.4)
  107 FORMAT(5X,8HXLOAD = E11.5,5X,7HXREM = ,E11.5,7X,
     . 6HC1(1)=,F6.3,5X,4H1/L=,F6.3)
  108 FORMAT(5X,I2,3X,E10.4,3X,E10.4,4X,E10.4,3X,E10.4,3X,E10.4,3X,
     . E10.4,3X,E10.4,3X,E10.4)
  109 FORMAT(4X,4HTANK,5X,3HMGD,8X,9HBOD USERS,3X,12HNITROSOMONAS
     . 2X,11HNITROBACTER,5X,3HBOD,8X,7HAMMONIA,6X,7HNITRITE,8X,4HVAER/)
  110 FORMAT(/4X,7HTIME = ,F6.2)
  111 FORMAT(1H1,'N=',I6,12X,'H=',F8.3,10X,'T=',F5.1,13X,
     . 'TD=',F5.1,10X,'NCALC=',I4,//,1X,
     . 'C1(1)=',F5.2,9X,'C2(1)=',F5.1,9X,'C3(1)=',F4.2,10X,'C4(1)=',
     . F4.2,//,1X,'C1(2)=',F4.2,10X,'C2(2)=',F4.2,10X,'C3(2)=',F4.2,10X,
     . 'C4(2)=',F5.3,//,1X,'C1(3)=',F4.2,10X,'C2(3)=',F4.2,10X,'C3(3)=',
     . F4.2,10X,'C4(3)=',F5.3,/)
  112 FORMAT(1X,'XRSS=',F7.4,8X,'URSS=',F4.2,11X,'Q(15)=',F5.3,
     . 9X,'CTEMP=',F6.2,5X,'AMP=',F7.3,8X,'TLAG=',F7.3,//,1X,'NTKS=',I2,
     . 13X,'VAER=',F5.2,10X,'V(2)=',F6.3,9X,'V(17)=',F5.3,///)
  114 FORMAT(10F10.3)
  115 FORMAT(1H1,//////)
      READ(IN,101) (SMATX(I),I=1,100)
      READ(IN,101) (QMATX(I),I=1,100)
      READ(IN,101) (UMATX(I),I=1,100)
      READ(IN,102) N,H,T,TD,TLAG,AMP,NCALC
      READ(IN,106) NTKS,VAER,V(2),V(17),CTEMP,Q(15),URSS,XRSS
      K=NTKS+3
      READ(IN,104) (C1(I),C2(I),C3(I),C4(I),I=1,3)
      READ(IN,103) (S(I,2),I=1,3)
      READ(IN,103) ((X(I,J),I=1,3),J=4,K)          Step input logic which
      READ(IN,103) ((S(I,J),I=1,3),J=4,K)          can be removed
      READ(IN,103) (X(I,17),I=1,3)
      READ(IN,103) (S(I,17),I=1,3)
      WRITE(IO,115)
      WRITE(IO,114) SMATX,QMATX,UMATX
      WRITE(IO,111) N,H,T,TD,NCALC,C1(1),C2(1),C3(1),C4(1),C1(2),C2(2),
     . C3(2),C4(2),C1(3),C2(3),C3(3),C4(3)
      WRITE(IO,112) XRSS,URSS,Q(15),CTEMP,AMP,TLAG,NTKS,VAER,V(2),V(17)
      T=.002
      DO 20 J=4,K
   20 V(J)=VAER/NTKS
      NSTOP=N+1
      CALL SCALF(3.,.04,TD,0.)
      DO 900 LL=1,NSTOP
      ICNT=ICNT+1
      Q(1)=QMATX(ICNT)
      S(1,1)=SMATX(ICNT)
```

Step input logic which can be removed and replaced with constant values or sine wave equations for S(1,1), S(2,1), Q(1), and URSS

```
      IF (T-TD) 50,30,30
   30 IF (ABS(T-TD)-.01) 40,45,45
   40 CALL FPLOT(0,T,Q(1))
   45 CALL FPLOT(2,T,Q(1))
   50 S(2,1)=18.
```

Plotter logic which can be removed or replaced

```
      S(3,1)=0.0
      X(1,2)=0.0
      X(2,2)=0.0
      X(3,2)=0.0
      XXL=VAER*X(1,K)/(Q(1)*S(1,1))
      C1(1)=6.457-4.434*(ALOG(XXL))
      C1(1)=C1(1)*1.047**(CTEMP-20.)
      IF(C1(1)) 60,60,70
   60 C1(1)=0.
   70 IF(V(2)) 100,80,100
```

C1(1) calculation logic

```
   80 S(1,2)=S(1,1)
      S(2,2)=S(2,1)
      S(3,2)=S(3,1)
      Q(2)=Q(1)
      GO TO 120
  100 Q(2)=10.
  120 DO 140 I=1,3
      X(I,14)=X(I,K)*XRSS
      X(I,15)=X(I,K)*URSS
  140 X(I,16)=X(I,K)*URSS
      DO 180 I=1,3
      S(I,14)=S(I,K)
      S(I,15)=S(I,K)
  180 S(I,16)=S(I,K)
```

Q(15) sine wave equation can be inserted here

```
      IF(V(17)) 220,200,220
  200 DO 210 I=1,3
      S(I,17)=S(I,16)
  210 X(I,17)=X(I,16)
  220 Q(16)=Q(2)*(1.-XRSS)/(URSS-1.)-Q(15)*(URSS-XRSS)/(URSS-1.)
      Q(17)=Q(16)
```

Q(17) sine wave equation can be inserted here

```
      IF(Q(17)) 240,280,280
  240 Q(17)=0.
  280 Q(3)=Q(2)+Q(17)
      Q(14)=Q(3)*(URSS-1.)/(URSS-XRSS)
      Q(16)=Q(3)-Q(14)-Q(15)
      DO 300 J=4,K
  300 Q(J)=Q(3)
      S(1,3)=(Q(2)*S(1,2)+Q(17)*S(1,17))/Q(3)
      S(2,3)=(Q(2)*S(2,2)+Q(17)*S(2,17))/Q(3)
      S(3,3)=Q(17)*S(3,17)/Q(3)
      X(1,3)=Q(17)*X(1,17)/Q(3)
      X(2,3)=Q(17)*X(2,17)/Q(3)
      X(3,3)=Q(17)*X(3,17)/Q(3)
      IF(M) 500,400,500
```

```
400 IF(T-TD) 480,420,420
420 WRITE(IO,110) T
    WRITE(IO,109)
    DO 440 L=1,K
440 WRITE(IO,108) L,Q(L),(X(M,L),M=1,3),(S(M,L),M=1,3),V(L)
    DO 460 L=14,17
460 WRITE(IO,108) L,Q(L),(X(M,L),M=1,3),(S(M,L),M=1,3),V(L)
    WRITE(IO,105) XXX(III)
    WRITE(IO,107) ZZZ(III),YYY(III),C1(1),XXL
480 M=NCALC
500 Q3=Q(3)
    Q16=Q(16)
    Q17=Q(17)
    V17=V(17)
    XXX(III)=Y
    YYY(III)=XREM
    ZZZ(III)=XLOAD
    III=III+1
    DO 520 J=4,K
    DO 520 I=1,3
520 DELX(I,J)=DXDTF(X(I,J-1),X(I,J),V(J),C1(I),S(I,J),C2(I),C3(I))
    DO 540 J=4,K
    DO 540 I=1,2
540 DELS(I,J)=DSDTF(S(I,J-1),S(I,J),V(J),C1(I),X(I,J),C2(I),C4(I))
    DO 550 J=4,K
550 DELS(3,J)=Q(3)*(S(3,J-1)-S(3,J))/V(J)-C1(3)*S(3,J)*X(3,J)/(C2(3)+
   . S(3,J))/C4(3)+C1(2)*S(2,J)*X(2,J)/(C2(2)+S(2,J))/C4(2)
    DELY=Q(14)*S(1,14)*8.33
    BUGS=V(17)*X(1,17)
    DO 560 I=4,K
560 BUGS=BUGS+V(I)*X(1,I)
    DELR=(Q(2)*S(1,2)-Q(14)*S(1,14))/BUGS
    DELL=Q(2)*S(1,2)/BUGS
    IF(V(17)) 570,610,570
570 DO 590 I=1,3
590 DLX17(I)=DX17F(X(I,16),X(I,17),C1(I),S(I,17),C2(I),C3(I))
    DO 600 I=1,2
600 DLS17(I)=DS17F(S(I,16),S(I,17),C1(I),X(I,17),C2(I),C4(I))
    DLS17(3)=(Q(16)*S(3,16)-Q(17)*S(3,17))/V(17)-C1(3)*S(3,17)*
   . X(3,17)/(C2(3)+S(3,17))/C4(3)+C1(2)*S(2,17)*X(2,17)/(C2(2)+
   . S(2,17))/C4(2)
    DLV17=Q(16)-Q(17)
610 IF(V(2)) 630,650,630
630 DELS2=(Q(1)*S(1,1)-Q(2)*S(1,2))/V(2)
    DELA2=(Q(1)*S(2,1)-Q(2)*S(2,2))/V(2)
    DLV2=Q(1)-Q(2)
650 IF(III-101) 690,670,670
670 III=1
690 Y=Y+DELY*H
    XXX(III)=Y-XXX(III)
    XREM=XREM+DELR*H
    YYY(III)=XREM-YYY(III)
    XLOAD=XLOAD+DELL*H
    ZZZ(III)=XLOAD-ZZZ(III)
    DO 700 J=4,K
    DO 700 I=1,3
    X(I,J)=X(I,J)+DELX(I,J)*H
```

The specified number of increments per day plus one must be used; for H = .01, the value of 101 is used here

```
700 S(I,J)=S(I,J)+DELS(I,J)*H
    IF(V(17)) 720,780,720
720 V(17)=V(17)+DLV17*H
    DO 760 I=1,3
    S(I,17)=S(I,17)+DLS17(I)*H
760 X(I,17)=X(I,17)+DLX17(I)*H
780 IF(V(2)) 800,810,800
800 S(1,2)=S(1,2)+DELS2*H
    S(2,2)=S(2,2)+DELA2*H
    V(2)=V(2)+DLV2*H
810 DO 850 J=4,K
    DO 850 I=1,3
    IF(S(I,J)-.001) 830,830,850
830 S(I,J)=0.0
850 CONTINUE
    DO 890 I=1,3
    IF(S(I,17)-.001) 870,870,890
870 S(I,17)=0.0
890 CONTINUE
    T=T+H
    M=M-1
    IF(ICNT-100) 900,895,900   --> Step input logic which can be removed
895 ICNT=0
900 CONTINUE
    CALL EXIT
    END
```

FIGURE I-6

```
N=   300             H=    0.010            T=  0.0                 TD=  0.0           NCALC=   1

C1(1)= 6.40          C2(1)=150.0            C3(1)=0.16              C4(1)=0.55

C1(2)=0.68           C2(2)=1.00             C3(2)=0.00              C4(2)=0.050

C1(3)=1.00           C2(3)=2.10             C3(3)=0.18              C4(3)=0.020

XRSS= 0.0112         LRSS=3.48              Q(15)=1.530             CTEMP= 26.39     AMP=  0.000       TLAG=  0.000

NTKS= 2              VAER=12.50             V(2)= 0.000             V(17)=0.000


 TIME =    0.00
 TANK      MGD          BOD USERS   NITROSOMONAS  NITROBACTER      BOD          AMMONIA       NITRITE         VAER

   1   0.6250E 02    0.0000E 00    0.0000E 00    0.0000E 00    0.1300E 03    0.1800E 02    0.0000E 00    0.0000E 00
   2   0.6250E 02    0.0000E 00    0.0000E 00    0.0000E 00    0.1300E 03    0.1800E 02    0.0000E 00    0.0000E 00
   3   0.8527E 02    0.6943E 03    0.8273E 01    0.0000E 00    0.9623E 02    0.1339E 02    0.4754E 01    0.0000E 00
   4   0.8527E 02    0.7420E 03    0.8700E 01    0.0000E 00    0.2030E 02    0.5100E 01    0.1340E 02    0.0000E 00
   5   0.8527E 02    0.7470E 03    0.8900E 01    0.0000E 00    0.3600E 01    0.7600E 00    0.1780E 02    0.6250E 01
  14   0.6097E 02    0.8366E 01    0.9968E-01    0.0000E 00    0.3600E 01    0.7600E 00    0.1780E 02    0.6250E 01
  15   0.1530E 01    0.2599E 04    0.3097E 02    0.0000E 00    0.3600E 01    0.7600E 00    0.1780E 02    0.0000E 00
  16   0.2277E 02    0.2599E 04    0.3097E 02    0.0000E 00    0.3600E 01    0.7600E 00    0.1780E 02    0.0000E 00
  17   0.2277E 02    0.2599E 04    0.3097E 02    0.0000E 00    0.3600E 01    0.7600E 00    0.1780E 02    0.0000E 00
 ACCUMULATED BOD AT STATION 14 = 0.00000E 00  LB
 XLOAD = 0.00000E 00     XREM = 0.00000E 00          C1(1)= 7.832     1/L= 1.149
 TIME =    0.01
 TANK      MGD          BOD USERS   NITROSOMONAS  NITROBACTER      BOD          AMMONIA       NITRITE         VAER

   1   0.6250E 02    0.0000E 00    0.0000E 00    0.0000E 00    0.1295E 03    0.1800E 02    0.0000E 00    0.0000E 00
   2   0.6250E 02    0.0000E 00    0.0000E 00    0.0000E 00    0.1295E 03    0.1800E 02    0.0000E 00    0.0000E 00
   3   0.8527E 02    0.6950E 03    0.8271E 01    0.0000E 00    0.9581E 02    0.1341E 02    0.4733E 01    0.0000E 00
   4   0.8527E 02    0.7424E 03    0.8691E 01    0.0000E 00    0.1806E 02    0.5242E 01    0.1320E 02    0.0000E 00
   5   0.8527E 02    0.7476E 03    0.8898E 01    0.0000E 00    0.3385E 01    0.8295E 00    0.1772E 02    0.6250E 01
  14   0.6097E 02    0.8374E 01    0.9966E-01    0.0000E 00    0.3385E 01    0.8295E 00    0.1772E 02    0.6250E 01
  15   0.1530E 01    0.2601E 04    0.3096E 02    0.0000E 00    0.3385E 01    0.8295E 00    0.1772E 02    0.0000E 00
  16   0.2277E 02    0.2601E 04    0.3096E 02    0.0000E 00    0.3385E 01    0.8295E 00    0.1772E 02    0.0000E 00
  17   0.2277E 02    0.2601E 04    0.3096E 02    0.0000E 00    0.3385E 01    0.8295E 00    0.1772E 02    0.0000E 00
 ACCUMULATED BOD AT STATION 14 = 0.18283E 02  LB
 XLOAD = 0.87306E-02     XREM = 0.84948E-02          C1(1)= 7.803     1/L= 1.154
 TIME =    0.02
 TANK      MGD          BOD USERS   NITROSOMONAS  NITROBACTER      BOD          AMMONIA       NITRITE         VAER

   1   0.6250E 02    0.0000E 00    0.0000E 00    0.0000E 00    0.1290E 03    0.1800E 02    0.0000E 00    0.0000E 00
   2   0.6250E 02    0.0000E 00    0.0000E 00    0.0000E 00    0.1290E 03    0.1800E 02    0.0000E 00    0.0000E 00
   3   0.8527E 02    0.6955E 03    0.8271E 01    0.0000E 00    0.9535E 02    0.1342E 02    0.4715E 01    0.0000E 00
   4   0.8527E 02    0.7421E 03    0.8683E 01    0.0000E 00    0.1735E 02    0.5364E 01    0.1304E 02    0.0000E 00
   5   0.8527E 02    0.7482E 03    0.8897E 01    0.0000E 00    0.3046E 01    0.8829E 00    0.1765E 02    0.6250E 01
  14   0.6097E 02    0.8380E 01    0.9965E-01    0.0000E 00    0.3046E 01    0.8829E 00    0.1765E 02    0.6250E 01
  15   0.1530E 01    0.2603E 04    0.3096E 02    0.0000E 00    0.3046E 01    0.8829E 00    0.1765E 02    0.0000E 00
  16   0.2277E 02    0.2603E 04    0.3096E 02    0.0000E 00    0.3046E 01    0.8829E 00    0.1765E 02    0.0000E 00
  17   0.2277E 02    0.2603E 04    0.3096E 02    0.0000E 00    0.3046E 01    0.8829E 00    0.1765E 02    0.0000E 00
 ACCUMULATED BOD AT STATION 14 = 0.35477E 02  LB
 XLOAD = 0.17421E-01     XREM = 0.16963E-01          C1(1)= 7.776     1/L= 1.160
```

APPENDIX II

TIME-DEPENDENT MEASUREMENTS TAKEN AT THE
HYPERION PLANT IN
LOS ANGELES, CALIFORNIA

★ U.S. GOVERNMENT PRINTING OFFICE: 1972— 759-395/75

TABLE II-1

DATE: 7-1-69

TIME	10:30	11:00	12:30	15:00	18:00	19:00				AVG.
PRIMARY EFFLUENT:										
Volume flow, mgd	50.	50.	50.	50.	50.	50.				50.
BOD_5, uf, mg/l		138.		168.		204.				170.
BOD_5, f, mg/l		90.		108.		126.				108.
COD, uf, mg/l					137.					
COD, f, mg/l										
NH_3 as N, mg/l				16.6	20.9					18.8
NO_3 as N, mg/l				1.6	.4					1.
PO_4, mg/l				9.9	8.3					9.1
SS, milli, mg/l		80.		104.		124.				102.6
SS, gooch, mg/l		74.		98.		100.				90.6
% volatile		97.3		91.8		86.				91.7
AERATOR EFFLUENT:										
Water temp., °F										78.
SS, gooch, mg/l		1810.		1940.		1950.				1900.
% volatile		71.8		70.1		70.8				70.9
NO_3 as N, mg/l					5.5					5.5
PO_4, mg/l					0.					0.
DO, inlet, ppm										1.
DO, outlet, ppm										2.
pH										7.1
RETURN SLUDGE STREAM:										
Return flow, mgd	22.	22.	22.	22.	22.	22.				22.
SS, gooch, mg/l		5680.		5800.		5920.				5800.
% volatile		72.2		71.7		69.6				71.2
Waste flow, mgd	.81	.81	.81	.81	.81	.81				.81
FINAL EFFLUENT:										
BOD_5, uf, mg/l		11.		7.		11.				9.6
BOD_5, f, mg/l		1.8		1.5		1.8				5.1
COD, uf, mg/l	16.		16.	16.	45.					23.2
COD, f, mg/l										
NH_3 as N, mg/l				.6	1.3					.95
NO_3 as N, mg/l				4.4	4.4					4.4
PO_4, mg/l				0.	0.					0.
SS, milli, mg/l		7.		6.		7.				6.6
SS, gooch, mg/l		8.		7.		7.				7.3
% volatile		100.		100.		100.				100.
Sludge blanket, ft	9.	9.	9.	9.	9.	9.				9.

DATE: 7-2-69

TABLE II-2

TIME	3:00	7:00	11:00	15:00	18:00	19:00	21:00	24:00		AVG.
PRIMARY EFFLUENT:										
Volume flow, mgd	50.	50.	50.	50.	50.	50.	50.			50.
BOD_5, uf, mg/l	186.	168.	144.	198.		210.				181.2
BOD_5, f, mg/l	114.	117.	84.	129.		147.				118.2
COD, uf, mg/l								145.		145.
COD, f, mg/l										
NH_3 as N, mg/l								15.7		15.7
NO_3 as N, mg/l								0.16		0.16
PO_4, mg/l								9.6		9.6
SS, milli, mg/l	124.	84.		152.		104.				116.
SS, gooch, mg/l	120.	78.		34.		26.				64.5
% volatile	86.7	97.4		94.1		100.				94.5
AERATOR EFFLUENT:										
Water temp., °F										78.
SS, gooch, mg/l	1940.	1980.	1800.	1750.		2090.				1912.
% volatile	71.6	69.2	68.3	67.4		74.6				70.2
NO_3 as N, mg/l										
PO_4, mg/l							0.0	0.0		0.0
DO, inlet, ppm										1.
DO, outlet, ppm										2.
pH										7.1
RETURN SLUDGE STREAM:										
Return flow, mgd	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2		21.2
SS, gooch, mg/l	5920.	6040.	6400.	6440.		6480.				6256.
% volatile	68.2	68.5	72.5	70.2		69.1				69.7
Waste flow, mgd	.66	.66	.66	.66	.66	.66	.66	.66		.66
FINAL EFFLUENT:										
BOD_5, uf, mg/l	21.	25.	8.5	7.0		11.5				14.6
BOD_5, f, mg/l	0.6	0.3	1.5	0.9		0.9				.84
COD, uf, mg/l					32.		32.	20.		28.
COD, f, mg/l										
NH_3 as N, mg/l					0.9		4.0	5.3		3.4
NO_3 as N, mg/l								3.8		3.8
PO_4, mg/l							0.0	0.0		0.0
SS, milli, mg/l	12.	19.	6.	6.		7.				10.
SS, gooch, mg/l	14.	20.	8.	8.		9.				11.8
% volatile	90.2	87.5	100.	100.		100.				95.5
Sludge blanket, ft	9.	9.	9.	9.	9.	9.	9.	9.		9.

DATE: 7-3-69

TABLE II-3

TIME	03:00	06:00	07:00	08:30	10:30	12:30	15:00	18:00		AVG.
PRIMARY EFFLUENT:										
Volume flow, mgd	49.	49.	49.	49.	49.	49.	49.	49.		49.
BOD_5, uf, mg/l	204.	180.								192.
BOD_5, f, mg/l	123.	108.								115.5
COD, uf, mg/l	141.	141.		141.	125.	148.				139.2
COD, f, mg/l										
NH_3 as N, mg/l	16.5	16.4		16.2	15.0	21.6	27.5	19.0		18.8
NO_3 as N, mg/l	.18	.12		.11	.06	.08	.10	.10		.11
PO_4, mg/l	10.1	9.7		9.6	7.1	7.8	7.4	9.4		8.7
SS, milli, mg/l										
SS, gooch, mg/l										
% volatile										
AERATOR EFFLUENT:										
Water temp., °F										79.
SS, gooch, mg/l	1880.		2060.							1970.
% volatile	68.1		69.9							69.
NO_3 as N, mg/l										
PO_4, mg/l	0.5	1.0		1.0	1.0	1.0	1.0	1.0		.93
DO, inlet, ppm										1.
DO, outlet, ppm										2.
pH										7.1
RETURN SLUDGE STREAM:										
Return flow, mgd	21.4	21.4	2.14	21.4	21.4	21.4	21.4	21.4		21.4
SS, gooch, mg/l	6320.		6340.							6330.
% volatile	68.4		70.0							69.2
Waste flow, mgd	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69		0.69
FINAL EFFLUENT:										
BOD_5, uf, mg/l	32.		15.							23.5
BOD_5, f, mg/l	1.5		1.2							1.4
COD, uf, mg/l	38.	28.		27.	27.	29.	29.	.24		28.8
COD, f, mg/l										
NH_3 as N, mg/l	5.9	4.5		2.1	1.0	0.0	0.0	0.0		1.9
NO_3 as N, mg/l	3.2	3.8		4.3	4.3	4.5	4.0	5.1		4.2
PO_4, mg/l	0.0	0.0		0.0	0.0	0.0	0.0	0.0		0.0
SS, milli, mg/l	25.		9.							17.
SS, gooch, mg/l	25.		10.							17.5
% volatile	100.		100.							100.
Sludge blanket, ft	9.	9.	9.	9.	9.	9.	9.	9.		9.

DATE: 7-8-69

TABLE II-4

TIME	03:00	06:00	08:30	10:30	12:30	15:00	18:00	21:00	24:00	AVG
PRIMARY EFFLUENT:										
Volume flow, mgd	50.	37.5	25.	50.	75.	100.	87.5	75.	62.5	62.5
BOD_5, uf, mg/1			132.	150.	126.	186.	192.	186.	168.	162.
BOD_5, f, mg/1			120.	111.	99.	138.	138.	141.	138.	126.
COD, uf, mg/1						110.	112.			111.
COD, f, mg/1										
NH_3 as N, mg/1					23.	27.	18.			22.6
NO_3 as N, mg/1					.16	.13	.10			.13
PO_4, mg/1					5.5	7.8	9.0			7.4
SS, milli, mg/1			76.	64.	76.	104.	116.	104.	96.	90.8
SS, gooch, mg/1			54.	54.	66.	84.	80.	78.	78.	70.6
% volatile			96.	89.	88.	95.	100.	90.	100.	94.
AERATOR EFFLUENT:										
Water temp., °F	80.	80.	80.	79.2	78.5	78.5	78.5	80.	80.	79.4
SS, gooch, mg/1			1820.	1920.	1750.	1680.	1800.	1740.	1840.	1792.8
% volatile			82.	80.	79.	78.	81.	80.	80.	80.
NO_3 as N, mg/1										
PO_4, mg/1					0.5	0.0	5.0			1.83
DO, inlet, ppm				0.7	0.4	0.7				.6
DO, outlet, ppm										
pH	7.15	7.05	7.00	7.05	7.05	7.00	7.00	7.05	7.10	7.05
RETURN SLUDGE STREAM:										
Return flow, mgd	22.0	22.0	21.7	21.7	21.7	21.5	21.5	21.5	22.0	21.7
SS, gooch, mg/1			3720.	5940.	7620.	8880.	8760.	7920.	7320.	7165.7
% volatile			82.	82.	78.	76.	76.	77.	79.	78.5
Waste flow, mgd	.87	.87	.87	.87	.87	.87	.87	.87	.87	.87
FINAL EFFLUENT:										
BOD_5, uf, mg/1			27.	19.	13.	9.	17.	26.	23.	19.1
BOD_5, f, mg/1			10.	10.	7.	9.	13.	14.	14.	11.
COD, uf, mg/1					21.		51.			36.
COD, f, mg/1										
NH_3 as N, mg/1					2.7	5.2	11.7			6.5
NO_3 as N, mg/1										
PO_4, mg/1					8.0	1.0	4.5			4.5
SS, milli, mg/1			39.	21.	15.	14.	21.	31.	25.	23.7
SS, gooch, mg/1				19.	12.	8.	23.	30.	25.	19.5
% volatile				100.	100.	100.	93.	97.	88.	96.3
Sludge blanket, ft	9.	9.	9.	9.	9.	9.	9.	9.	9.	9.

DATE: 7-9-69

TABLE II-5

TIME	03:00	06:00	08:30	10:30	12:30	15:00	18:00	21:00	24:00	AVG.
PRIMARY EFFLUENT:										
Volume flow, mgd	50.	37.5	25.	50.	75.	100.	87.5	75.	62.5	62.5
BOD_5, uf, mg/l	198.	180.	174.	180.	186.	180.	210.	216.	204.	192.
BOD_5, f, mg/l	126.	132.	84.	90.	84.	93.	96.	11.4	102.	102.
COD, uf, mg/l									199.	199.
COD, f, mg/l										
NH_3 as N, mg/l								16.5	16.0	16.2
NO_3 as N, mg/l								.08	.04	.06
PO_4, mg/l							9.3	8.5	8.8	8.9
SS, milli, mg/l	84.	72.	108.	124.	108.	124.	116.	124.	104.	107.
SS, gooch, mg/l	66.	56.	70.	52.	72.	90.	92.	86.	72.	72.8
% volatile	94.	89.	46.	58.	53.	58.	80.	65.	67.	67.7
AERATOR EFFLUENT:										
Water temp., °F	80.	80.	79.7	79.2	79.0	78.5	78.7	80.0	80.0	79.4
SS, gooch, mg/l	2000.	1940.	1930.	2020.	1960.	1700.	1650.	1860.	2300.	1928.8
% volatile	77.	77.	79.	73.	75.	76.	81.	81.	80.	77.6
NO_3 as N, mg/l							0.0	0.0	0.0	0.0
PO_4, mg/l							8.0	5.0	10.5	7.8
DO, inlet, ppm										
DO, outlet, ppm										
pH	7.0	6.45	6.45	7.10	6.95	6.90	6.85	7.05	7.05	6.86
RETURN SLUDGE STREAM:										
Return flow, mgd	21.5	21.5	21.5	21.5	21.5	21.5	21.5	26.0	26.0	22.5
SS, gooch, mg/l	6280.	5160.	3260.	5500.	7460.	8560.	8660.	7860.	7880.	6735.5
% volatile	77.	78.	81.	79.	78.	79.	79.	76.	79.	78.4
Waste flow, mgd	.67	.67	.67	.67	.67	.67	.67	.67	.67	.67
FINAL EFFLUENT:										
BOD_5, uf, mg/l	28.	26.	11.	14.	11.	8.	12.	21.	21.	17.
BOD_5, f, mg/l	13.	12.	2.1	2.1	3.0	2.1	2.4	2.7	1.8	4.6
COD, uf, mg/l							59.	59.	59.	59.
COD, f, mg/l										
NH_3 as N, mg/l							7.0	15.8	14.1	12.3
NO_3 as N, mg/l							0.0	0.0	0.0	0.0
PO_4, mg/l							7.0	11.0	14.0	10.6
SS, milli, mg/l	26.	28.	28.	30.	26.	17.	25.	34.	35.	27.6
SS, gooch, mg/l	20.	22.	11.	17.	12.	14.	21.	34.	35.	20.6
% volatile	90.	84.	48.	82.	57.	48.	81.	69.	89.	72.
Sludge blanket, ft	9.	9.	9.	9.	9.	9.	9.	9.	9.	9.

DATE: 7-10-69

TABLE II-6

TIME	03:00	06:00	08:30	10:30	12:30	15:00	18:00	21:00	24:00	AVG.
PRIMARY EFFLUENT:										
Volume flow, mgd	50.	37.5	25.	50.	75.	100.	87.5	75.	62.5	62.5
BOD$_5$, uf, mg/l	198.	192.	150.	150.	132.	174.	186.			168.8
BOD$_5$, f, mg/l	105.	108.	108.	105.	93.	117.	132.			109.7
COD, uf, mg/l	204.	170.	143.	107.	121.	179.	170.			156.3
COD, f, mg/l										
NH$_3$ as N, mg/l	16.0	15.7	14.3	14.3	13.0	22.4	20.0			16.5
NO$_3$ as N, mg/l	.05	.09	.08	.08	.06	.08	.05			.07
PO$_4$, mg/l	8.7	8.6	7.0	6.6	4.7	8.1	9.4			7.6
SS, milli, mg/l	84.	100.	76.	100.	88.	124.	116.			98.2
SS, gooch, mg/l	78.	70.	28.	58.	74.	84.	86.			68.2
% volatile	77.	54.	100.	93.	97.	88.	100.			87.
AERATOR EFFLUENT:										
Water temp., °F	80.	80.	80.	79.2	79.0	79.0	79.0	80.	80.	79.6
SS, gooch, mg/l	2230.	2240.	1940.	2090.	1870.	1790.	1890.			2007.
% volatile	74.	75.	87.	87.	85.	85.	84.			82.4
NO$_3$ as N, mg/l	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0
PO$_4$, mg/l	7.0	6.5	11.9	8.0	6.0	5.0	2.5			6.7
DO, inlet, ppm						1.4				1.4
DO, outlet, ppm										
pH	7.0	7.0	6.92	7.0	7.0	6.95	7.0	7.0		6.98
RETURN SLUDGE STREAM:										
Return flow, mgd	26.0	26.0	26.0	26.0	26.0	26.0	30.0	30.0	30.0	27.3
SS, gooch, mg/l	5960.	4500.	4100.	5600.	7180.	7840.	7080.			6037.
% volatile	80.	76.	88.	85.	85.	82.	82.			82.6
Waste flow, mgd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FINAL EFFLUENT:										
BOD$_5$, uf, mg/l	28.	17.	18.	22.	20.	16.	19.			20.
BOD$_5$, f, mg/l		1.2	6.3	6.9	6.0	4.8	5.4			5.1
COD, uf, mg/l	54.	54.	59.	68.	51.	55.	42.			54.7
COD, f, mg/l										
NH$_3$ as N, mg/l	12.3	11.5	8.5	8.0	7.6	6.2	11.0			9.3
NO$_3$ as N, mg/l	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0
PO$_4$, mg/l	11.0	10.0	14.9	11.0	5.0	4.0	6.5			8.9
SS, milli, mg/l	27.	34.	27.	29.	24.	24.	38.			29.
SS, gooch, mg/l	29.	27.	14.	20.	16.	15.	18.			19.8
% volatile	85.	76.	96.	98.	97.	100.	100.			93.1
Sludge blanket, ft	9.	9.	9.	9.	9.	9.	9.	9.	9.	9.